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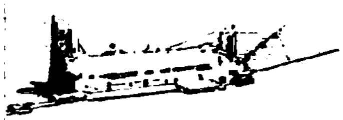

DREDGING RESEARCH PROGRAM

TECHNICAL REPORT DRP-92-7

TYLERS BEACH, VIRGINIA, DREDGED MATERIAL PLUME MONITORING PROJECT 27 SEPTEMBER TO 4 OCTOBER 1991

edited by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
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The Dredging Research Program (DRP) is a seven-year program of the US Army Corps of Engineers. DRP research is managed in these five technical areas:

Area 1 - Analysis of Dredged Material Placed in Open Water

Area 2 - Material Properties Related to Navigation and Dredging

Area 3 - Dredge Plant Equipment and Systems Processes

Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems

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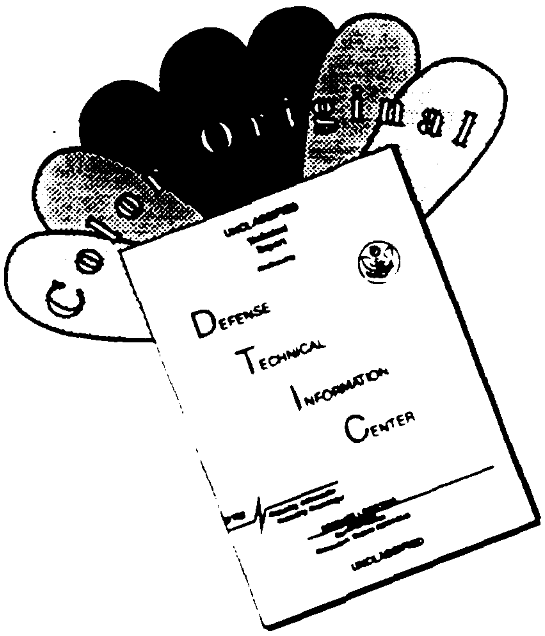

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Dredging Research Program Report Summary

Analysis of Dredged Material Placed in Open Water

Tylers Beach, VA, Dredged Material Plum Monitoring Project (TR DRP-92-7)

ISSUE: The Corps' Norfolk District has responsibility for dredging Tylers Beach Federal Project to maintain a small navigation channel located on the James River in Virginia. The dredging/disposal operation takes place about every eight years. The disposal site is adjacent to Point of Shoals, a large natural oyster seeding ground that is unique to the region.

A 1981 conventional monitoring study combined with information from physical and mathematical models indicated that the site would be physically and environmentally suitable for the placement of dredged material. However, in the planning phase of recent (1991) maintenance operations, environmental agencies expressed concern about the possibility of dredged material reaching Point of Shoals and adversely affecting the oyster grounds.

RESEARCH: The Dredging Research Program (DRP) has developed monitoring equipment and techniques that make possible the synoptic measurement of currents and movement of dredged material discharged at an open-water disposal site. The DRP includes a continuing effort to provide guidance and to further develop methods, procedures, and equipment for monitoring sediment plumes associated with dredging operations.

SUMMARY: During the disposal operations, the DRP was able to show that the discharged material reached the placement site and then moved along the bottom in a relict river channel. Acoustic monitoring did not detect any dredged material migrating into the Point of Shoals area, and water samples showed no alteration of suspended material above background measurements made on Point of Shoals before the dredging operations.

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13. ABSTRACT *(Maximum 200 words)*

The Tylers Beach, Virginia, Dredged Material Plume Monitoring Project (TBMP) was conducted during the period 27 September to 4 October 1991. The project was conducted under the Dredging Research Program Technical Area 1, entitled "Analysis of Dredged Material Placed in Open Water," in support of the U.S. Army Engineer District, Norfolk. The objectives of the TBMP were to (a) collect suspended material concentration data and current data to determine the potential for dredged material issuing from a pipeline discharge to reach environmentally sensitive areas adjacent to the placement site, and (b) continue development of PLUmes MEasurement System (PLUMES) for monitoring dredged material plumes. This report provides an overview of the equipment and procedures used during the TBMP, together with a presentation of the TBMP data and analysis results. The TBMP produced an extensive, high-quality data set from 12 acoustic surveys and numerous suspended material and bottom grab samples. Components of the TBMP include:

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acoustic backscatter measurements from an Acoustic Doppler Current Profiler; water current measurements from two systems; in situ water sampling; monitoring of ambient conditions; and accurate ship positioning. Under calm weather conditions such as those encountered during the project, the discharge of dredged material at the placement site did not cause an increase in the naturally occurring concentration of suspended material on an oyster seeding ground called Point of Shoals.

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Acoustic Doppler Current Profiler (ADCP)
Dredged material
James River
PLUme MEasurement System (PLUMES)
Point of Shoals
Suspended material

PREFACE

The study described herein was authorized as part of the Dredging Research Program (DRP) by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and was partially supported by the U.S. Army Engineer District, Norfolk (USAED, Norfolk). Work was performed under the Measurement of Entrainment and Transport Work Unit 32464 and the Cohesive Sediment Processes Work Unit 32590 of DRP Technical Area 1 (TA1), "Analysis of Dredged Material Placed in Open Water," at the Coastal Engineering Research Center (CERC) and Hydraulics Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES). Messrs. Robert H. Campbell and Glenn R. Drummond were the HQUSACE Chief and TA1 Technical Monitors, respectively, for the DRP. Mr. E. Clark McNair, Jr., CERC, was DRP Program Manager (PM), and Dr. Lyndell Z. Hales, CERC, was Assistant PM. Dr. Nicholas C. Kraus, Senior Scientist, CERC, was Technical Manager of DRP TA1. Dr. Kraus was Principal Investigator (PI) of Work Unit 32464 during the conduct of the data collection, and Ms. Michelle M. Thevenot, Coastal Processes Branch (CPB), Research Division (RD), CERC, was PI during report preparation. Mr. Allen M. Teeter, Hydraulic Engineer, Estuarine Processes Branch (EPB), Estuaries Division, HL, was the PI of Work Unit 32590.

This report describes field activities and data analysis results from a DRP field data collection project conducted at the James River off Tylers Beach, Virginia, between 27 September and 4 October, 1991. The investigators who participated in the data collection project were: Ms. Terri L. Prickett, CPB; Messrs. Ramon G. Cabrera and Craig A. Huhta, RD Flow, San Diego, California; and Messrs. Thad C. Pratt and Samuel E. Varnell, EPB. Onsite coordination and assistance were provided by Mr. Ronald G. Vann, Chief, Civil Programs, Engineering Division (EngD), USAED, Norfolk, and Mr. Thomas D. Woodward, Jr., Project Management Section (PMS), USAED, Norfolk. The crew of the survey boat *Lynnhaven*, Survey Section, USAED, Norfolk, were Mr. William J. Simmons, Captain; Mr. Anthony J. Smith, survey party chief; Mr. Kevan R. Taylor, survey technician; and Mr. Edwin T. Williams, electronics technician. Mr. Gray Smith, CPB, assisted in the data collection. Mr. Gary Dill, videographer from the WES Information Technology Laboratory (ITL), Visual Production Center, Photography Section, documented the project on videotape and assisted in taking still photographs. During the project, visitors who came aboard the *Lynnhaven* to observe and review monitoring procedures included: Messrs. Thomas A. Barnard, Jr. and Walter I. Priest III, Virginia Institute of Marine Science; Mr. Charles R. Roadley, Jr., Virginia

Marine Resource Commission; Mr. Elliott E. Whitehurst, Chief, PMS, USAED, Norfolk; and Mr. James N. Thomason, Chief, EngD, USAED, Norfolk.

This report was written over the period November 1991 to September 1992 by the investigators who participated in the data collection project and their colleagues. Part I was written by Ms. Prickett, who coordinated preliminary production of all chapter contributions, and Mr. Teeter. Part II was written by Mses. Prickett and Thevenot, and Messrs. Pratt, Teeter, and Cabrera. Part III was written by Ms. Thevenot, Messrs. Cabrera and Teeter, Ms. Prickett, and Mr. Huhta. Part IV was written by Dr. Kraus. Appendices A and C were written by Mr. Teeter. Appendices B and D were written by Mses. Thevenot and Prickett. Appendix E was written by Messrs. Huhta and Cabrera and Ms. Prickett, and Appendix F was written by Ms. Prickett, Mr. Cabrera, and Ms. Thevenot. Ms. Thevenot coordinated the technical content and preparation of the final report, and Dr. Kraus provided input to and technical review of all chapters. This report also benefitted from the technical review provided by Dr. Paul R. Ogushwitz, PRO Scientific, Denville, New Jersey. Mses. Holley Messing and Marsha Darnell, CPB, assisted in report formatting and physical production. Ms. Janean Shirley, ITL, was publications editor of the final report.

Mses. Prickett and Thevenot were under the supervision of Mr. Bruce A. Ebersole, Chief, CPB. Messrs. Pratt and Teeter were under the supervision of Mr. George M. Fisackerly, Chief, EPB. This study was conducted under the general supervision of Dr. James R. Houston, Director, CERC; Messrs. Charles C. Calhoun, Jr., Assistant Director, CERC; H. Lee Butler, Chief, RD, CERC; Frank A. Herrmann, Jr., Director, HL; Richard L. Sager, Assistant Director, HL; and William H. McAnally, Chief, Estuaries Division, HL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

Additional information can be obtained from Mr. E. Clark McNair, Jr., DRP Program Manager, at (601) 634-2070 or Ms. Michelle M. Thevenot, Principal Investigator, at (601) 634-3301.

CONTENTS

PREFACE 1

LIST OF TABLES 5

LIST OF FIGURES 6

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT 8

SUMMARY 9

PART I: INTRODUCTION 10

- Background 10
- Site Description 12
- Dredging Operations 14
- Plume Dispersion Model 16
- Scope of Report 16

PART II: EQUIPMENT AND PROCEDURE 17

- Weather 18
- Monitoring Equipment 19
- Field Procedure 24
- Laboratory Analysis Procedures 34

PART III: RESULTS 38

- Water Temperature 38
- Salinity 39
- Bed Sediments 43
- Current Measurements 46
- Suspended Material Concentration 50

PART IV: CONCLUSIONS 79

- Discussion 79
- Conclusions 80

REFERENCES 83

APPENDIX A: DISPERSION ANALYSIS FOR PIPELINE DISCHARGE A1

- Introduction A1
- Descent of a Dense Plume to the Bed A3

Entrainment from an Underflow A5
Passive Dispersion A11
Results for Tylers Beach Pipeline Discharge A12
Discussion of Fluid Mud Entrainment A17

APPENDIX B: SUSPENDED MATERIAL CONCENTRATION, SALINITY, AND CURRENT SPEED AND DIRECTION B1

APPENDIX C: BOTTOM SEDIMENT SAMPLE GRAIN SIZE C1

APPENDIX D: TRANSMISSOMETER CONCENTRATION PROFILES D1

APPENDIX E: ACOUSTIC SURVEY LOCATION MAPS E1

APPENDIX F: SUMMARY OF ACOUSTIC SURVEYS F1

Background Surveys, 30 September 1991 . . . . F1
Surveys During Dredging Operations, 1 October 1991 . . . . F2
Surveys During Dredging Operations, 2 October 1991 . . . . F4
Surveys During Dredging Operations, 3 October 1991 . . . . F6

APPENDIX G: NOTATION G1

LIST OF TABLES

No.		Page
1	Project Schedule	12
2	Major Monitoring Equipment	18
3	Wind Information From Notes	20
4	Statistical Summary of CTD Recorded Salinity	43
5	Frequency of Current Ranges	49
6	Mean Current Speed, ft/sec	49
7	Statistical Summary of Suspended Material	55
8	2.4-MHz BBADCP Concentration Measurements	66
A1	Calculated Underflow Thickness and Spreading Rates	A14
A2	Fixed-Volume Viscous Spreading Rates	A15
A3	Calculated Entrainment Rates	A16
A4	Passive Dispersion of Dredged Material for 100-g/sec Release Rate 225 m Downstream of Release	A18
B1	CTD Depth, Temperature, and Salinity (Team 1)	B2
B2	Temperature, Salinity, and Depth Taken at Rescue Marina	B9
B3	Suspended Material Concentration, Salinity, and Current Speed and Direction (Team 1)	B20
B4	Suspended Material Concentration, Salinity, and Current Speed and Direction (Team 2)	B28
B5	Automatic Water Sampler Suspended Material Concentration and Salinity (Station 2.5 and 4.5)	B35
E1	Starting and Ending Times for Survey Legs	E2

LIST OF FIGURES

No. Page

1 Location map for Tylers Beach 13
2 Location of dredged material placement site 14
3 Hydraulic cutterhead dredge used at the dredging site 15
4 Configuration of discharge pipeline at the placement site 15
5 Norfolk District survey vessel *Lynnhaven* 17
6 Schematic of acoustic instrument mounting and beam configuration 20
7 CTD ready for deployment 22
8 Bed sediment grab sampler 22
9 Instrumentation assembly for current measurements used by Team 2 23
10 Transmissometer mounted on sampling cage 24
11 Closeup of transmissometer used during the TBMP 25
12 Automatic water sampler 25
13 Schematic of deployed automatic water sampler 26
14 Location of water sampling and CTD profiling stations 27
15 Collection of water samples 27
16 Deployment of CTD 28
17 Locations of bottom grab samples before and during dredging 29
18 Arrangement of acoustic instruments prior to deployment 30
19 Computer systems attached to acoustic instruments for viewing data 30
20 Acoustic instruments deployed from the *Lynnhaven* 31
21 Schematic of acoustic tracking procedures 32
22 Location map for Team-2 sample stations 33
23 Time series of salinity (30 September) 39
24 Time series of salinity (1 October) 40
25 Range of salinity near the project site 41
26 Pre-dredging sediment mean phi size contours 44
27 Mean phi size contours of sediments collected during dredging operations 45
28 Median settling speeds from column settling tests 46
29 Water elevation at Rescue Marina 48
30 Time series of suspended material concentration (30 September) 52
31 Time series of suspended material concentration (1 October) 53
32 Pre-dredging suspended material distributions from all Team-2 stations 56
33 Suspended material distribution from all Team-2 stations during dredging operations 56
34 Pre-dredging and dredging water sample distributions 57
35 Paired scatter plots of suspended material concentration, current speed and direction, and depth at Station 4 58
36 Transmissometer field and laboratory calibration curve 60
37 BBADCP field and laboratory calibration curves 67
38 Background acoustic profile along channel during ebb tide 69
39 Background acoustical data during peak flood tide 70
40 Cross-channel survey leg showing dredged material discharge at discharge point during peak ebb tide 72
41 Cross-channel survey leg of acoustic data during plume monitoring, south of discharge point during ebb tide 73

42 Dredged material discharge at discharge point during slack water 74
43 Cross-channel survey leg taken at slack water during a period of no dredging 75
44 Cross-channel survey leg near discharge point during peak flood tide 77
A1 Three dispersion phases of discharge from a pipeline A2
A2 Schematic of underflow characteristics A7
A3 Example of cohesive sediment settling relationships A9
A4 Field observations of concentration versus current speed A19

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	25.4	millimeters
miles (US statute)	1.609347	kilometers
ounces (US fluid)	0.02957353	cubic decimeters
pounds (mass)	0.4535924	kilograms

SUMMARY

This report describes activities and analysis results for a data collection project conducted off Tylers Beach in the James River, Virginia, to monitor the movement of dredged material placed with a single-point pipeline discharge. The dredged material placement site is adjacent to Point of Shoals, a major oyster seeding ground in the Chesapeake Bay Estuary, an area of environmental concern. The dredged material was monitored using the PLUmes MEasurement System (PLUMES) under development by the Dredging Research Program Technical Area 1 (TA1), "Analysis of Dredged Material Placed in Open Water," of the U.S. Army Corps of Engineers. The PLUMES consists of acoustic instrumentation to measure the water velocity and sediment concentration by remote sensing. In situ water and sediment sampling procedures were employed for direct analysis and verification of the acoustic measurements.

The Tylers Beach, Virginia, Dredged Material Plume Monitoring Project (TBMP), was conducted during the period 27 September to 4 October 1991 by two TA1 work units and the U.S. Army Engineer District, Norfolk. The objectives of the TBMP were: (a) to collect sediment concentration and current data to determine the potential for dredged material to reach Point of Shoals, and (b) to continue development of PLUMES monitoring procedures for dredged material plumes. The schedule of the TBMP included 2 days of background monitoring prior to dredging operations, and 3 days of monitoring during dredging operations.

Twelve acoustic surveys were made during the TBMP, and numerous suspended material and bottom grab samples were collected. Data collection also included measurements of current, salinity, and transmissivity. The background data showed that during tidal phases of ebb and flood, when current speeds were high, bottom sediment was resuspended into the water column. Sediment resuspension, particularly in the shallower areas and on Point of Shoals, is related, in part, to ambient wind conditions. During dredging operations, the dredged material reached the placement site and then moved along the bottom in the relict channel. Acoustic monitoring did not detect dredged material migrating onto Point of Shoals, and water samples showed no alteration of suspended material on Point of Shoals.

Tylers Beach, Virginia, Dredged Material Plume Monitoring Project, 27 September to 4 October 1991

PART I: INTRODUCTION[1]

Background

1. At the request of the U.S. Army Engineer District, Norfolk, in the fall of 1991, personnel from the U.S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) and Hydraulics Laboratory (HL) conducted a field data collection project to monitor sediment plumes formed from dredged material placement off Tylers Beach, located along the James River, Virginia. The field data collection was supported by the Norfolk District, and the analysis and report preparation were supported by Dredging Research Program (DRP) work units involved with measurement and prediction of the movement of dredged material. This report describes the Tylers Beach project operations and results of subsequent data analyses.

2. The Norfolk District has, as one of its responsibilities, maintenance dredging of the Tylers Beach Federal Project, a small navigation channel located on the James River. The concurrent dredging and placement operation takes place approximately every 8 years. The placement site for the dredged material is located adjacent to Point of Shoals, a large, natural oyster seeding ground unique to the region. In 1981, the Norfolk District conducted a monitoring study (DeLoach, Getchell, and Waring 1982) to determine the physical and environmental suitability of the site for the placement of dredged material. Results from the 1981 monitoring study, combined with additional information gained from physical and mathematical models, indicated the site would be suitable for placement of dredged material without adversely impacting shellfish on Point of Shoals if the dredged material were discharged at a single point by a pipeline with a downward vertical attachment. In the planning phase of recent maintenance dredging operations, however, environmental agencies expressed concern about the possibility of dredged material reaching Point of Shoals and adversely affecting the oyster ground. This issue prompted the Norfolk District to seek guidance from the DRP and to use newly developed monitoring equipment to provide synoptic measurement of the current and movement of dredged material discharged at the placement site.

[1]Written by Ms. Terri L. Prickett and Mr. Allen M. Teeter.

3. The DRP Technical Area 1 (TA1) work unit "Measurement of Entrainment and Transport" (MET) is developing the PLUme MEasurement System (PLUMES) that includes an acoustic device designed to detect sediment concentration in the water column, measure the three-dimensional (3-D) current field, and record the ship position by bottom tracking (Kraus and Thevenot 1992; Kraus, Thevenot, and Lohrmann 1992). The PLUMES was field tested in Mobile, Alabama, in 1989 (Kraus and Prickett 1989; Kraus 1991) and in Miami Beach, Florida, in 1990 (Tsai et al. 1992). At those two projects, dredged material was released at the offshore placement sites by hopper barge and hopper dredge, respectively. In both cases, sediment plumes formed by the placement of dredged material offshore were successfully tracked using the PLUMES and associated monitoring procedures.

4. Use of acoustic instruments in dredged material plume monitoring, in particular, commercially available Fathometers, to detect dredged material plumes dates to the mid-1970's (e.g., Proni et al. 1976; Bokuniewicz et al. 1978). More recently, Nichols, Diaz, and Schaffner (1990) made in situ measurements and acoustic surveys of dredged material plumes issuing from hopper dredge overflows at a dredging operation at Rappahannock Shoals in central Chesapeake Bay. The acoustic survey revealed features of the geometry and dynamics of the plume, but concentration information was not obtained acoustically. Panageotou and Halka (1990) monitored dredged material plumes from a pipeline at a placement site near Pooles Island in the upper Chesapeake Bay. Sediment concentration measured with an optical transmissometer was qualitatively related to acoustic return to distinguish portions of the plumes with concentrations greater or less than 30 to 50 mg/ℓ. No direct calibration of the acoustic instrumentation appears to have been made in any other dredged material study known to the authors, except that determined in an earlier PLUMES proof of concept study at Mobile, Alabama (Kraus 1991).

5. The Tylers Beach, Virginia, Dredged Material Plume Monitoring Project (TBMP), was conducted during the period 27 September to 4 October 1991, by the TA1 MET work unit and the Norfolk District. RD Flow (RDF), a private company involved in development of the PLUMES under contract with the MET, operated the associated acoustic instrumentation. The main objective of the TBMP was to collect wide-area suspended material concentration and current data with the PLUMES to determine the potential for dredged material to reach Point of Shoals. This field deployment also provided the opportunity to continue development of monitoring procedures for dredged material plumes under diverse conditions. As part of the PLUMES, in situ suspended material samples and current measurements were taken by personnel from HL for verification of the acoustic-based measurements and as backup in the event of equipment failure. The "Cohesive

Sediment Processes" work unit under TA1 contributed to the analysis of in situ data and to modeling of the sediment plume. Two days of background monitoring prior to dredging operations and 3 days of monitoring during dredging operations were performed. The schedule of the TBMP is given in Table 1.

Table 1

Project Schedule

Date, 1991	Activity
27 September	Equipment mobilization
28 September	Transit to project site and equipment tests
29-30 September	Background monitoring
1-2 October	Plume monitoring
3 October	Field calibration and equipment demobilization
4 October	Transit from site

6. The strategy of the TBMP was to obtain information for in situ samples to independently characterize the movement of dredged material near the placement site; supplemental detailed synoptic measurements of the water velocity and sediment concentration could then be obtained with acoustic instrumentation. In situ measurements are commonly used to characterize physical processes at a placement site. However, single-point measurements provide limited information regarding the spatial and temporal dynamics of the discharge plume. This information, which includes the location of the plume boundaries, can be obtained from synoptic measurements taken acoustically. Because acoustic readings of suspended material concentration must undergo calibration, in situ samples are required to convert sound intensity to concentration.

Site Description

7. The James River is located in southeastern Virginia and flows southeast into Chesapeake Bay (Figure 1). The sedimentology, morphology, and circulation in the James River Estuary have been recently discussed by Nichols, Johnson, and Peebles (1991). The Tylers Beach Federal Project, comprising a small harbor and navigation channel, is situated on the western shore of the James River

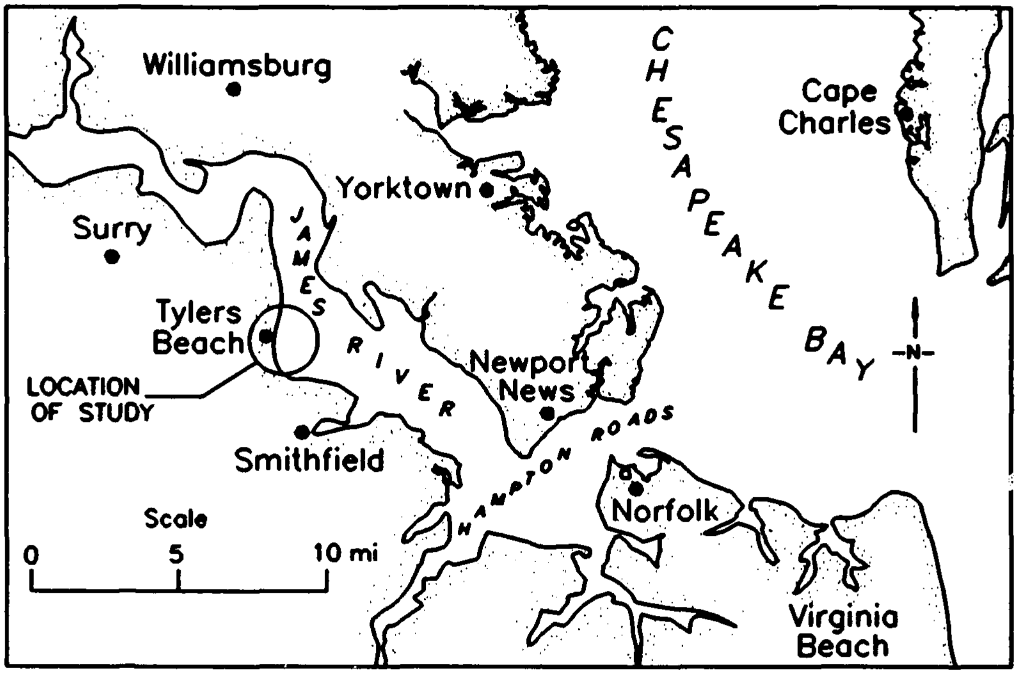

Figure 1. Location map for Tylers Beach

in Isle of Wight County, in an embayment of the river known as Burwell Bay, located approximately 13 miles[2] upstream from Chesapeake Bay (Figure 2). The James River in the Tylers Beach area is approximately 5 miles wide, and a large rock reef known as Point of Shoals is located approximately 1 mile offshore and to the east of Tylers Beach. The shoal, a unique feature in the area, is an oyster seeding ground. The James River at Tylers Beach experiences tidal fluctuations and current reversals.

8. The original (natural) channel in Burwell Bay curved to the southwest and around Point of Shoals. The curved channel posed a hazard to navigation. At the turn of the century, the U.S. Army Corps of Engineers created a straight, hydraulically self-maintaining channel through Point of Shoals. Since construction of the new channel, the original channel has become relict. The dredged material placement site, with an area of about 50 acres, is located approximately 1 mile from the Tylers Beach navigation channel in the deepest section of the relict channel ($\approx$ 30-ft depth mean low water, mlw) and is bounded by Point of Shoals to the east (Figure 2). The datum mlw is defined to be 1.17 ft below National Geodetic Vertical Datum (NGVD).

[2]A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 8.

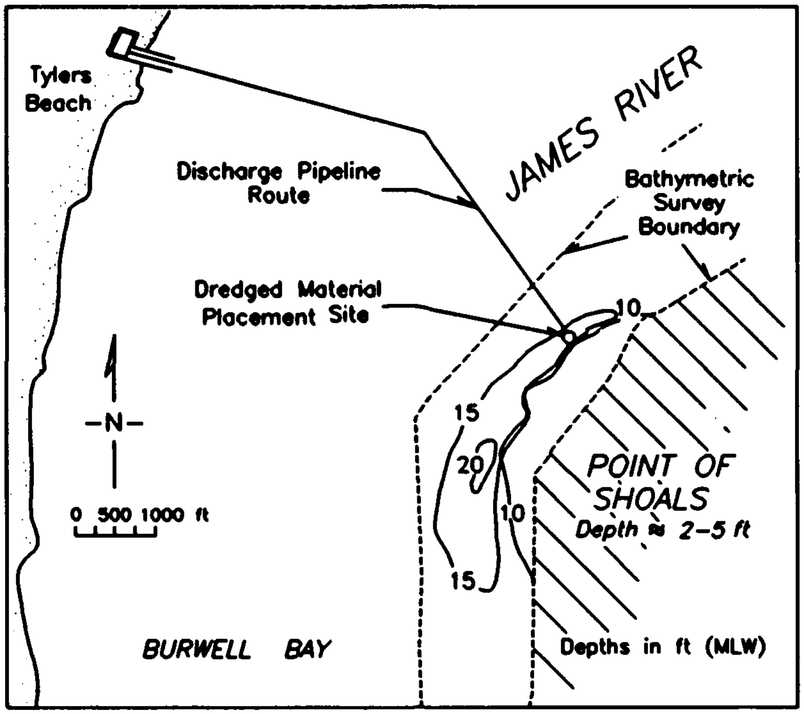

Figure 2. Location of dredged material placement site

Dredging Operations

9. Maintenance dredging was performed at the Tylers Beach Federal Navigation Project during the period 1-5 October 1991, by the *Richmond* (Figure 3), a hydraulic cutterhead dredge operated by Cottrell Engineering Corporation. Approximately 4,500 to 7,500 ft of 12-in.-diam discharge pipeline was attached to the dredge. A 90-deg elbow was connected to the end of the pipeline to which additional pipe was attached, forming a vertical section extending approximately 15 ft below the water surface referenced to mlw (Figure 4). A conical diffuser was affixed to the end of the vertical section and bent at an angle of 15 deg from the vertical to provide greater accuracy in depositing the dredged material at the placement site. Dredging was conducted in 24-hr operations, and approximately 18,000 cu yd of material were removed from the navigation channel and deposited at the placement site.

Figure 3. Hydraulic cutterhead dredge used at the dredging site

Figure 4. Configuration of discharge pipeline at the placement site

Plume Dispersion Model

10. Subsequent to the field study, a fluid dynamic description of discharged material was developed as part of DRP research activities. The analytical model is presented in Appendix A. The purpose of the analytic investigation was to evaluate predictive techniques for fluid mud entrainment from an underflow in support of field observations. Field observations with detailed measurements such as those made in the TBMP are lacking. The availability of this data provided an opportunity to test and refine plume dispersion models. Three phases of material behavior were analyzed sequentially:

a. The discharge plume descent.

b. Underflow spreading and entrainment of underflow material by the overlying flow.

c. Passive dispersion.

The discharge plume was predicted to descend directly to the bed with a four-fold increase in volume and to create a 0.2-m-thick underflow over the bed. Compared to TBMP results, the analysis overestimated entrainment from the underflow; several possible adjustments were proposed to improve the technique. Insights gained in model development and testing as described in Appendix A improve understanding of the monitoring results.

Scope of Report

11. This report describes equipment and procedures used at the TBMP and presents results of subsequent data analyses. Equipment and measurement procedures used are described in Part II. Part III presents results from analysis of both acoustic and in situ data. Part III also presents the results of field and laboratory calibration of the acoustic instruments. Part IV gives the conclusions. Appendix A gives a plume dispersion analysis and applies it to interpret the Tylers Beach data. Appendix B contains tables listing suspended material concentration, salinity, and current speed and direction values for individual sampling stations. Appendix C contains bottom sediment grain size results, and Appendix D gives vertical profiles of transmissivity measurements converted to sediment concentration. Transect maps in Appendix E provide position information obtained during acoustic surveys. Appendix F contains individual summaries of all acoustic surveys, and Appendix G is a listing of symbols employed in this report.

PART II: EQUIPMENT AND PROCEDURE[1]

12. Two teams were formed to conduct the TBMP. Team 1 acoustically monitored the project site onboard the *Lynnhaven* (Figure 5), a 40-ft-long hydrographic survey vessel provided by the Norfolk District. Team 1 members were comprised of personnel from CERC, RDF, and the crew of the *Lynnhaven*. A videographer from WES accompanied Team 1 and documented activities at the project. Still photographs were also taken. Measurements of conductivity, temperature, and depth (CTD) were made, and samples of suspended material and bed sediments were taken by Team 1. Team 2 was formed of personnel from HL who measured suspended material, transmissivity, and current velocity along vertical profiles through the water column at four fixed locations from a 20-ft HL vessel, the *WES-10*. The equipment used by both teams is listed in Table 2.

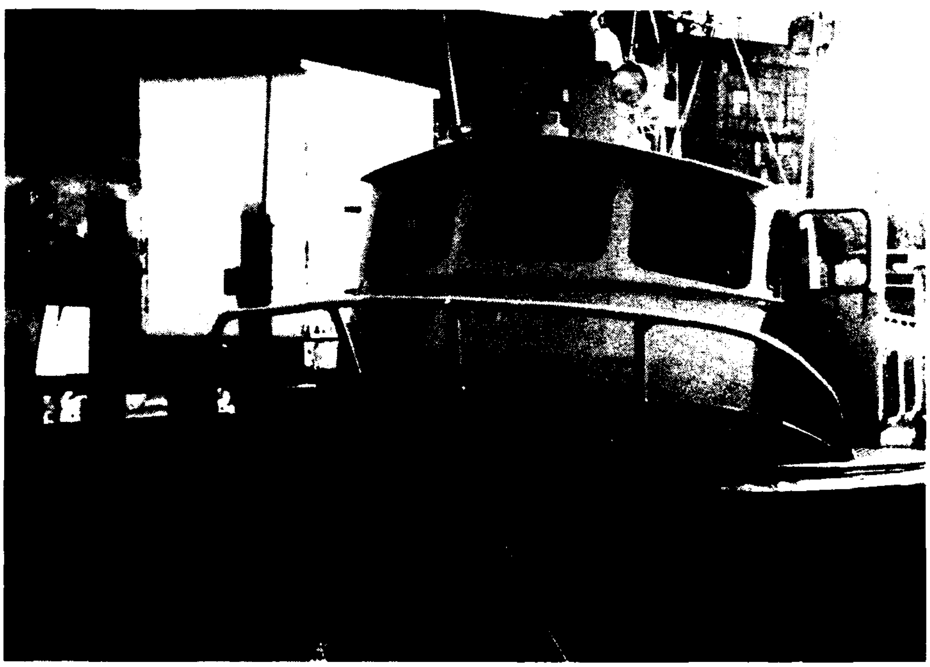

Figure 5. Norfolk District survey vessel *Lynnhaven*

[1]Written by Mses. Terri L. Prickett and Michelle M. Thevenot, Messrs. Thad C. Pratt, Allen M. Teeter, and Ramon G. Cabrera.

Table 2

Major Monitoring Equipment

Equipment	Type of Sample	Equipment Usage Number of Days Background	During Placement
	Team 1		
2.4-MHz Broad-Band Acoustic Doppler Current Profiler (BBADCP)	Backscatter strength, current speed and direction	2	3
600-kHz modified BBADCP	Backscatter strength	2	3
Submersible data logger (CTD recorder)	Conductivity, temperature and depth	2	1
Peristaltic water pump and tubing	Suspended material	2	2
Clamshell grab sampler	Bed sediment	1	1
	Team 2		
Gurley cup-type current and compass	Current speed and direction	1	2
Peristaltic water pump and tubing	Suspended material (discrete)	1	2
Automatic water samplers (2)	Suspended material (composite)	1	2
Aanderaa salinometer	Salinity	1	2
Transmissometer (10-cm length)	Transmissivity	-	3

Weather

13. Weather conditions during the project were ideal for the field measurement program. Days were mainly sunny, and the river was calm throughout the monitoring period. Weather forecasts on 2 October predicted a storm coming out of the northeast would arrive at the project area by evening. Intensive collection of acoustic data, suspended material samples, and bottom grab samples was

conducted under the assumption the weather would make conditions too rough to take measurements and samples on 3 October, the last scheduled day of the monitoring project. The storm did move through during the night, but, by the time the *Lynnhaven* reached the project site on the morning of 3 October, the river was sufficiently calm to continue monitoring operations.

14. The typical wind conditions during the monitoring period, shown in Table 3, consisted of calm weather during the morning with only a slight breeze, with wind speeds increasing to as much as 12 mph later in the afternoon. Exceptions to this norm occurred at 0843 Eastern Daylight Time (EDT) on 1 October when a 5-mph southeasterly wind was noted and on 3 October when the wind was strong in the morning (noted to be 12 mph from the northeast at 0945 EDT) and decreased into the afternoon. Wind measurements were made onboard the *Lynnhaven*. Shipboard anemometer readings were verified by the captain who monitored the weather conditions via radio broadcasts and had previous experience in determining the absolute wind speed and direction from the relative information taken aboard the boat.

Monitoring Equipment

Navigation

15. The *Lynnhaven* housed a Racal Micro-Fix Navigation System that operated with three associated shore stations. The range accuracy of the navigation system is ± 1 m. Navigation data were recorded at 1-sec intervals for later merging with acoustic data. Ship tracks were output to a pen plotter during monitoring operations.

Acoustic instrumentation

16. Team 1 monitored the sediment plume with two acoustic instruments. The first and primary acoustic system was an RD Instruments 2.4-MHz Broad-Band Acoustic Doppler Current Profiler (BBADCP). The 2.4-MHz system collected 3D velocity vectors to obtain current profiles in the water column together with backscatter levels to determine the position of the sediment plume and estimate sediment concentrations. Each beam was oriented 60 deg relative to the horizontal, at 90-deg azimuth intervals (Figure 6). A depth resolution of 50 cm was used for measuring current velocities. The beam pointing away from the ship, the port beam, was the single beam used for measuring backscatter strength. The 2.4-MHz system has a maximum depth range of approximately 8 m, a minimum depth resolution of 10 cm, and a dynamic range of about 80 dB for backscatter measurements. Because the acoustic beam spreads as it leaves the transducer face, the ensonified

Table 3

Wind Information From Notes

Date	Time	Wind Speed and Direction
9/29	0757	Wind light and variable (from NE in a.m., and SE in p.m.)
	p.m.	5 mph from the S
9/30	a.m.	Calm in the morning
	1500	10 mph from NE
	1547	12 mph from NE
10/1	0843	5 mph from the SE in ebb current
	0952	2 mph from the W-SW
	1124	Winds are below 2 mph (calm)
	1342	6 mph from the SE
	1600	10 mph from the S-SE
	1840	CALM
10/2		3 mph (calm)
	1600	5 mph (Weather prediction of the storm)
10/3	0945	12 mph from the NE

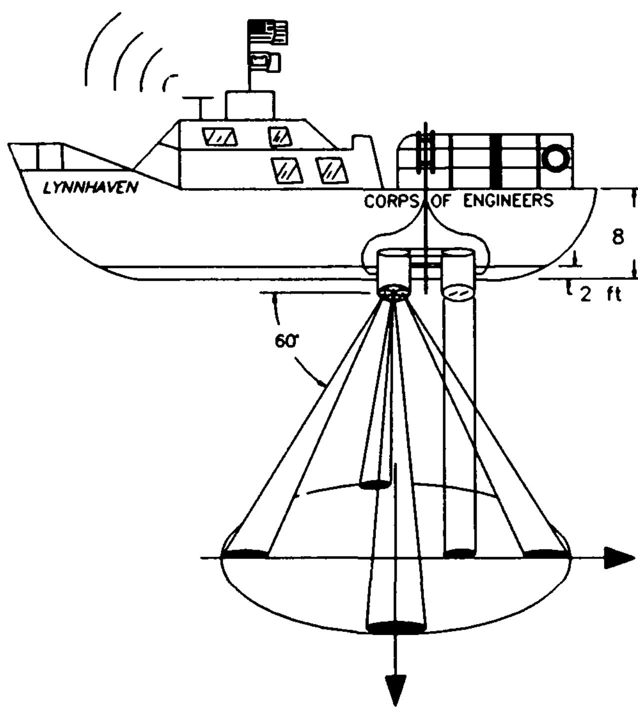

Figure 6. Schematic of acoustic instrument mounting and beam configuration

volume, the volume over which backscatter strength is averaged, was approximately 600 cm^3 at a distance of 1 m, but 15,500 cm^3 at a distance of 10 m. This system was interfaced with a digital compass and used bottom tracking to calculate ship speed, which allowed for real-time calculation of absolute velocity. A prototype of the PLUMES data acquisition software, running on a 386-processor personal computer (PC), controlled the operation of the 2.4-MHz system. This software provided real-time display of backscatter intensity and water velocity profiles along the track of the ship from which the crew was able to identify the location of the dredged material plume.

17. The second acoustic system was a 600-kHz test transducer, a modified BBADCP, consisting of a single beam mounted in the vertical direction. This system is under development by the MET work unit and measured backscatter levels in 10-cm vertical bins with a dynamic range of 40 dB. The ensonified volume at a distance of 1 m from the 600-kHz transducer is approximately 2,500 cm^3 and 20,500 cm^3 at 10 m. A simplified version of the PLUMES software, housed on a separate 386-processor PC from the 2.4-MHz transducer, controlled the operation of the 600-kHz system and also allowed display of backscatter amplitude along the ship track. A graphic representation of the beam configurations for both systems is given in Figure 6.

In situ samples

18. Team 1 obtained CTD measurements with a Seabird submersible data logger (Figure 7). A 1/2-in. OD line, attached to the upper end of the data logger, was marked in 1-ft increments to determine the depth of the instrument. Lead weights were attached to the lower end of the data logger to increase vertical stability in strong currents. A cable from the CTD recorder was run to the cabin and attached to a computer system for data logging. Water samples for measurement of suspended material were collected by use of 1/4-in. ID plastic tubing attached to a peristaltic water pump powered by a 12-Vdc battery. The sampling tube ($\approx$ 30-ft length) was affixed to the line used to lower the CTD recorder. The end of the tubing was located approximately 1 ft below the depth sensor on the CTD. Bottom sediment samples from the project site were taken with a Petersen-type grab sampler (Figure 8).

19. Team 2 measured current speed with a Gurley vertical-axis cup-type impeller velocity meter which has a threshold speed of 0.2 ft/sec and an accuracy of $\pm$0.1 ft/sec for flows greater than 1 ft/sec. Current direction was obtained to an accuracy of $\pm$2.0 deg. Attached to the solid suspension bar was a sampling tube assembly which collected water samples in a manner similar to those collected by Team 1. This instrument assembly was connected to a streamlined lead weight that held the sensors in a vertical position and oriented them into the direction of the flow. The signal

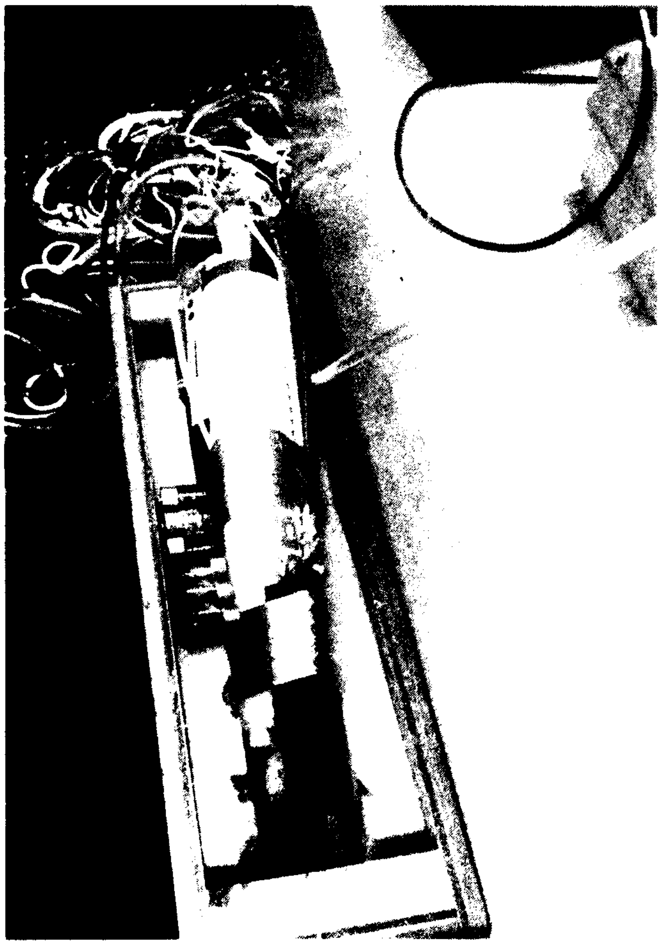

Figure 7. CTD ready for deployment

Figure 8. Bed sediment grab sampler

cables from each instrument were raised and lowered with the equipment and connected to display units located on the deck of the boat. The instrument array was deployed over the side of the boat using a portable equipment setup (Figure 9) consisting of a collapsible aluminum frame for support and a winch (with 1/8-in. wire rope) to raise and lower the equipment. An indicator on the winch displayed the depth of the instruments below the water surface.

20. Figure 10 shows a cage containing an array of in situ sampling devices. Measurements that can be obtained from this system include conductivity, temperature, depth, pH, dissolved oxygen, and transmissivity. Due to a malfunction in the instrument array, only transmissivity could be recorded during the project. Figure 11 shows the 10-cm transmissometer that was included in the instrument array and used in the TBMP. Two automatic water samplers (Figure 12) were deployed in floating platforms that were secured to the bottom with 150-lb concrete blocks and 13-lb anchors to ensure that their location did not change due to tide or wave action. A strainer, to which the end of the sampling tube was attached, floated approximately 1.5 ft above the site bottom. Both automatic water samplers were equipped with twenty-four 1-ℓ bottles and an internal computer operated with a

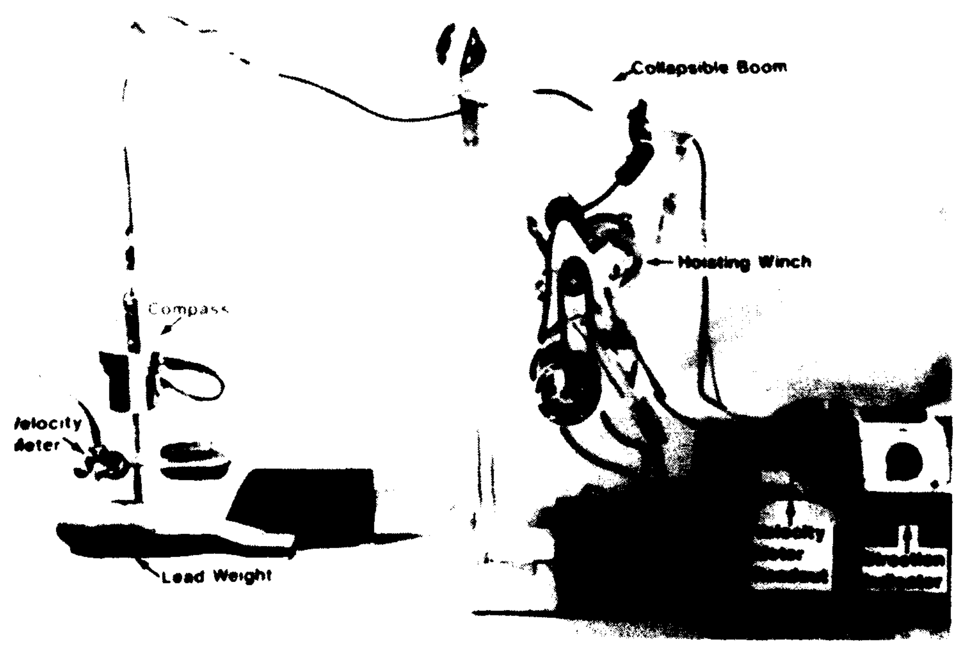

Figure 9. Instrumentation assembly for current measurements used by Team 2

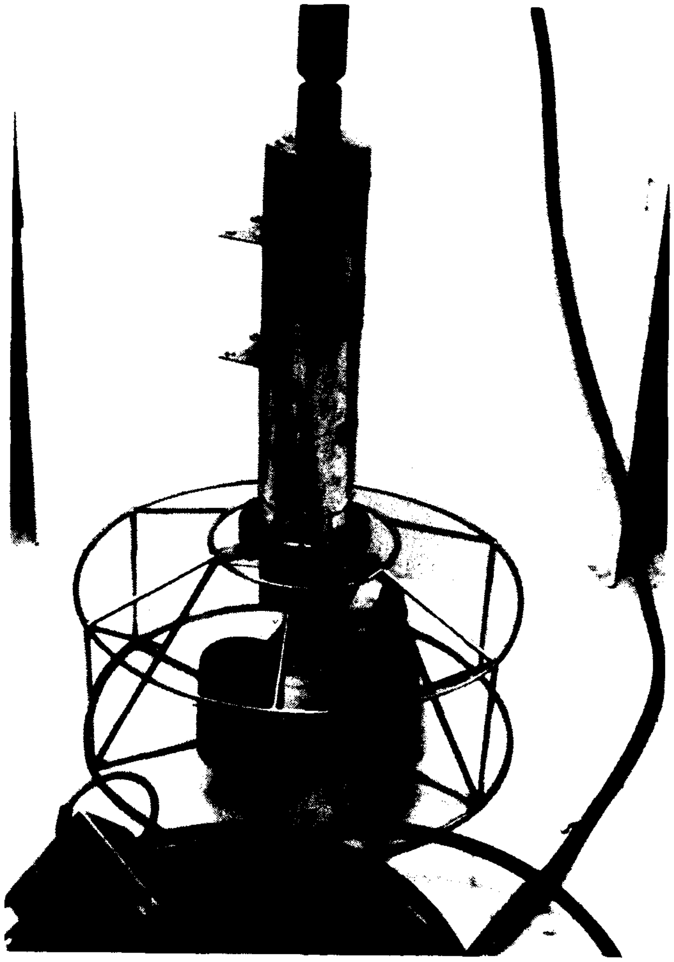

Figure 10. Transmissometer mounted on sampling cage

12-Vdc power source. Figure 13 shows the automatic water sampler assembly after deployment. Water surface elevations as well as temperature and conductivity were recorded using an Environmental Devices Corporation (ENDECO) CTD recorder, and salinity values were recorded with a portable Aanderaa salinity meter.

Field Procedure

21. On 29 September, the first monitoring day of the project, no acoustical measurements were made because of instrument preparation and adjustments for the extreme shallow-water site. However, Team 1 monitored ambient conditions in the relict channel and on Point of Shoals.

Figure 11. Close-up of transmissometer used during the TBMP

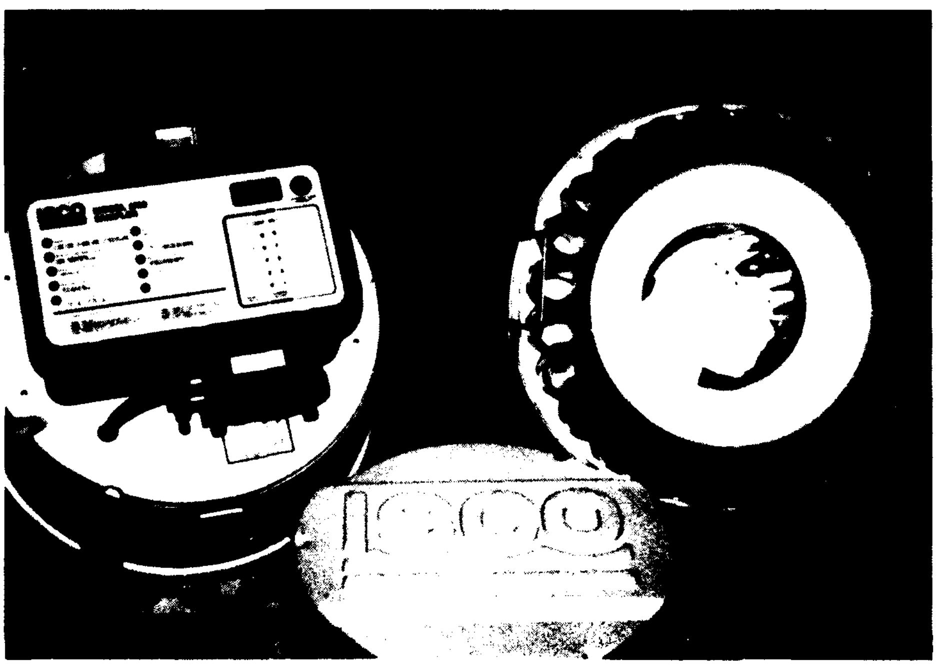

Figure 12. Automatic water sampler

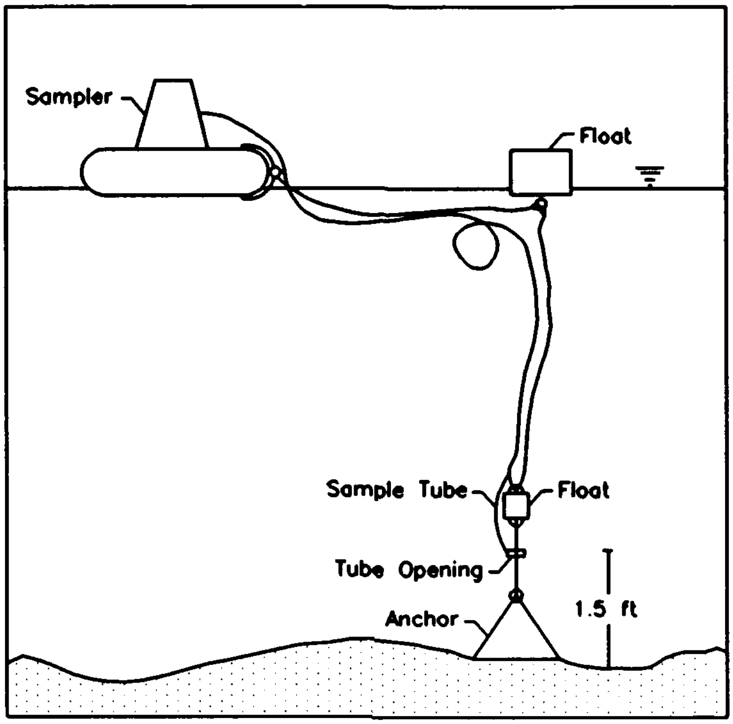

Figure 13. Schematic of deployed automatic water sampler

Water samples and CTD profile records were taken at 35 stations (locations shown on Figure 14) along the N-S transects at approximately 500-ft intervals for a distance extending approximately 2,000 ft north and south of the discharge point, and at 1,000-ft intervals further away from the discharge point. The CTD readings were taken at 15-sec intervals.

22. Water samples were obtained by Team 1 at elevations approximately 1 ft from the bottom, mid-water column, and 1 ft from the water surface. In some shallow areas (≈ 5-ft depth), no mid-water column samples could be taken. The pump and sampling tube were flushed for approximately 1 min at each depth before collecting the sample. The water was pumped through the sampling tube to the deck of the boat where each sample was collected in individual 8-oz plastic bottles (Figure 15). The sample bottles were labelled with the date, navigation coordinates, time of sampling, and depth at which the sample was taken (the depth of the sample was corrected with the addition of 1 ft to the measured depth to account for the distance from the depth sensor to the location of the end of the sampling tube). The suspended material samples were sealed, placed in coolers, and iced to prevent false increases in suspended material caused by biological growth.

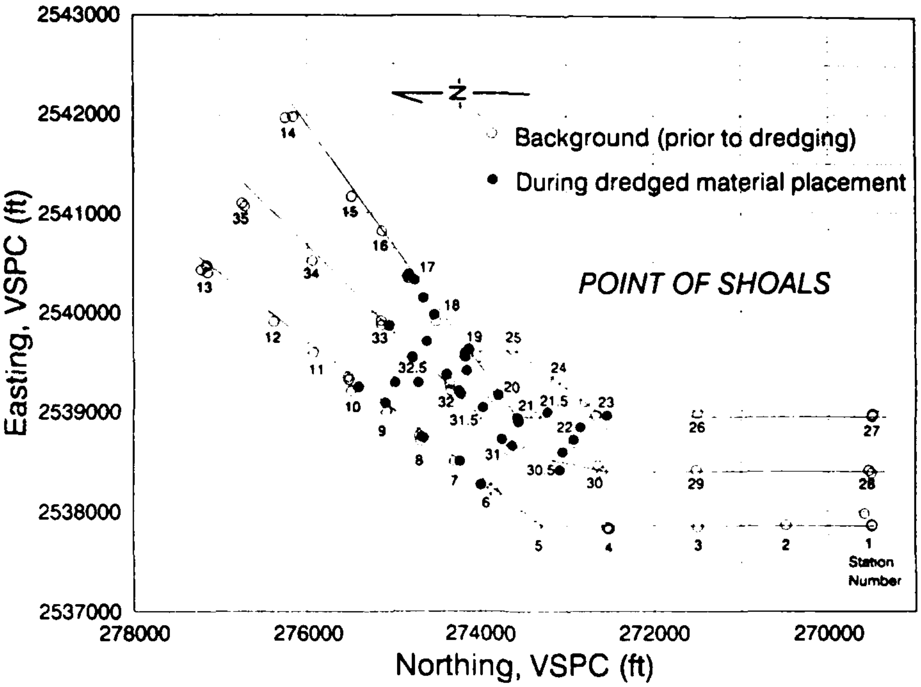

Figure 14. Location of water sampling and CTD profiling stations

Figure 15. Collection of water samples

23. When a designated station was reached, the *Lynnhaven* pulled to a stationary position, and a signal was given (a horn blast) to proceed with sampling. The instruments were immediately lowered over the port side of the *Lynnhaven*, and a CTD profile and water samples were collected. Figure 16 shows the CTD recorder and water sampling tube being lowered over the side of the *Lynnhaven*.

24. The Petersen grab sampler was manually lowered to the bottom off the stern of the *Lynnhaven* and a bottom sediment sample was collected. The sampler was then lifted back on deck, and a portion of the sediment sample was spooned into 8-oz containers and labelled with pertinent information (date, navigation coordinates, and time of sampling). The remaining sediment was then

Figure 16. Deployment of CTD

washed from the sampler with river water, and the *Lynnhaven* moved to the next sampling station. Bottom grab samples were taken at 18 stations on 30 September during background monitoring operations. Figure 17 shows the stations where the grab samples were taken. Water samples and CTD profile records were obtained simultaneously with the grab samples.

25. On 30 September, the same procedure was followed by Team 1 for taking in situ samples. In addition, acoustic surveys were made. The acoustic data included observation of the spatial variation in naturally suspended material and vertical stratification in the water column during extreme periods of tidal flow (flood, ebb, slack). The two acoustic systems were attached side by side to a 3-in. steel pipe (Figure 18), and anchored with a bracket to a wooden mount attached to the railing on the port side of the *Lynnhaven*, at approximately amidships. The arrangement was then secured with guide ropes. Figure 6 also shows the mounting arrangement for the acoustic instruments and its position on the *Lynnhaven*. The transducer faces of both acoustic systems were lowered to approximately 2 ft below the water surface. Cables from the instruments were run to the cabin of the *Lynnhaven* and attached to the two computers controlling the systems (Figure 19). The acoustic

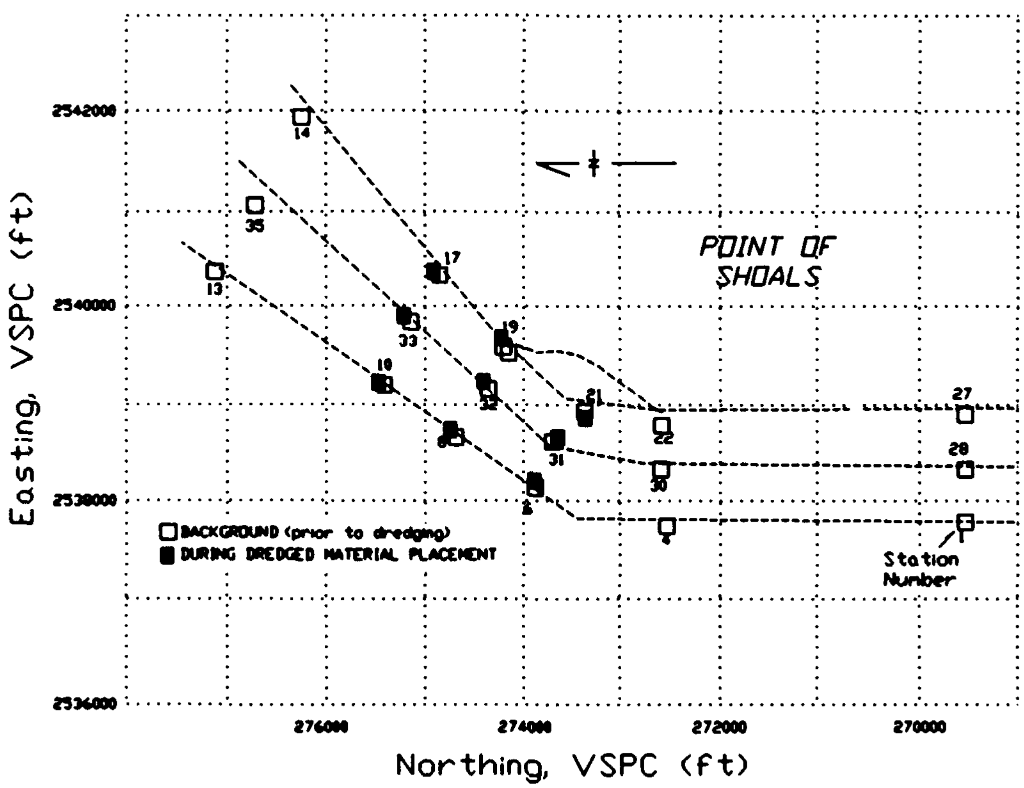

Figure 17. Locations of bottom grab samples before and during dredging

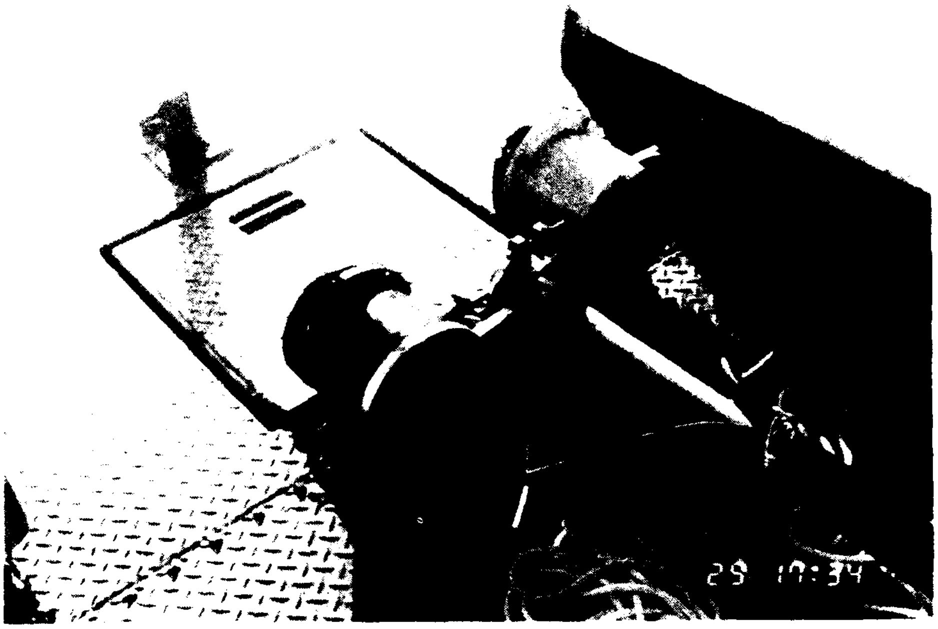

Figure 18. Arrangement of acoustic instruments prior to deployment

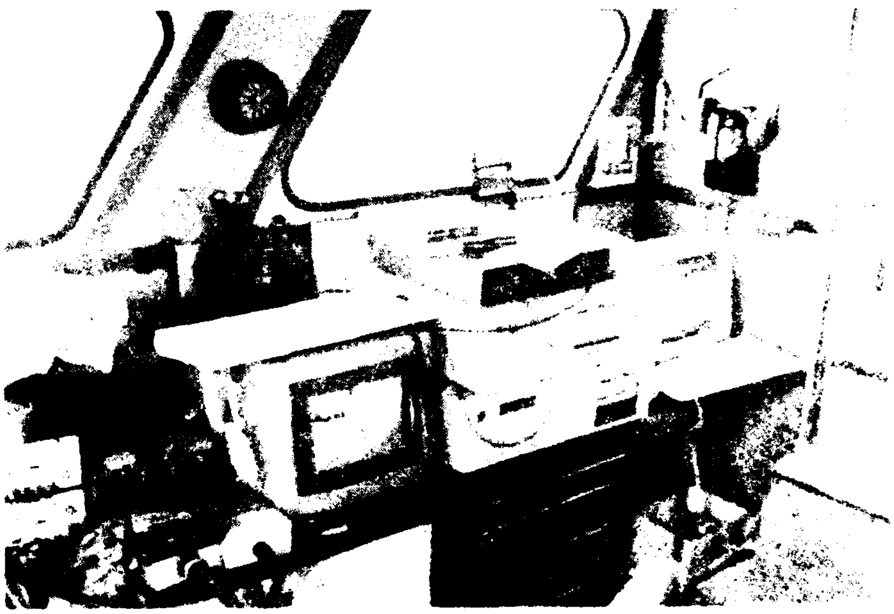

Figure 19. Computer systems attached to acoustic instruments for viewing data

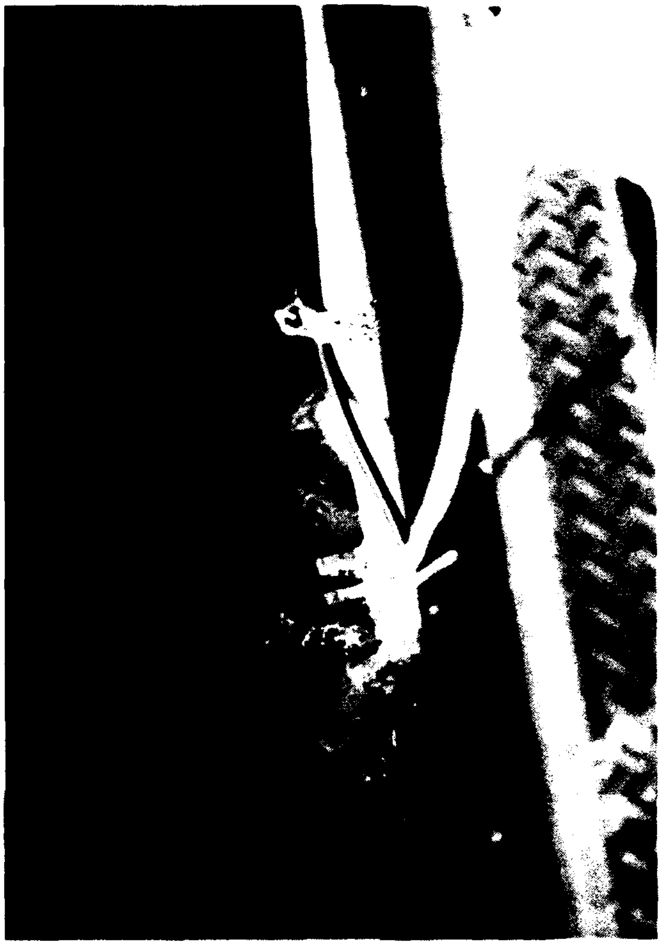

Figure 20. Acoustic instruments deployed from the *Lynnhaven*

instrumentation was deployed on the morning of each day (Figure 20) and removed when data collection was completed at the end of the day.

26. Three 8,000-ft monitoring transects were charted before monitoring began (see Figure 21); the transects encompassed the discharge point (the central reference point) and Point of Shoals, and extended approximately north and south of the discharge point, following the natural course along the relict channel. The location of the westernmost transect corresponded to the limit of the most recent bathymetric survey, located in the vicinity of the 10-ft contour. The eastern transect marked the topographic boundary between the channel and Point of Shoals, and the central transect ran through the deepest part of the channel, including the location of the discharge point.

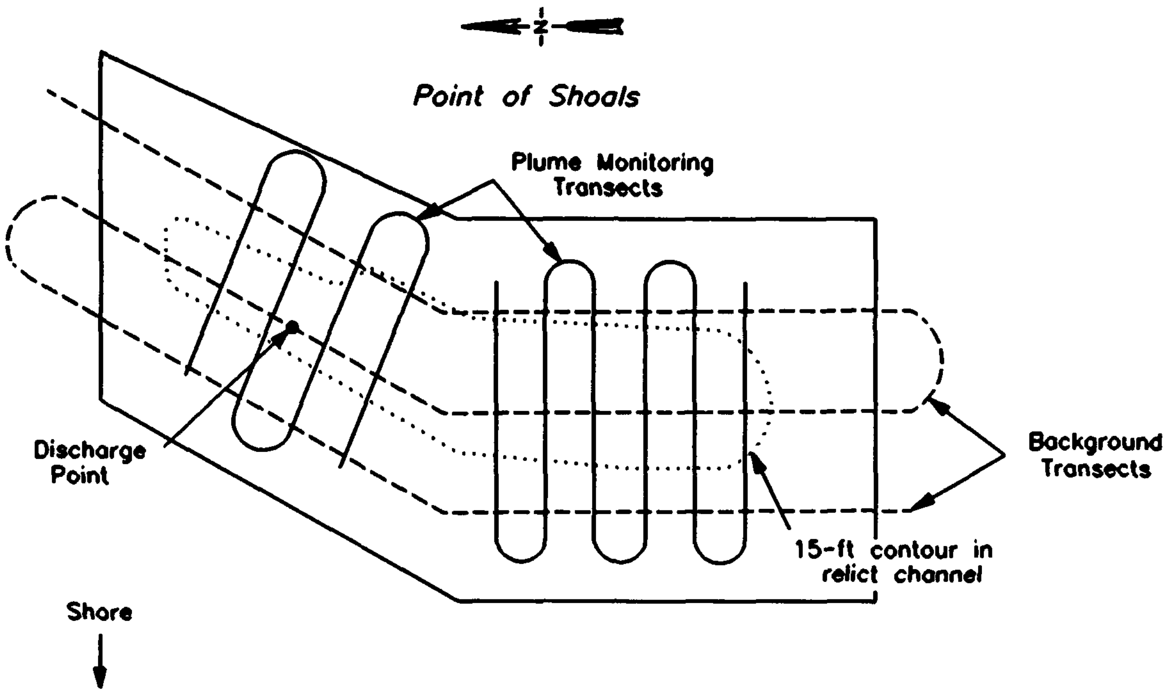

Figure 21. Schematic of acoustic tracking procedures

27. Team 2 began monitoring on 30 September. Current velocities, water samples, and salinity measurements were taken at a nominal distance of 2 ft from the bottom, mid-water column, and 2 ft from the water surface at two stations (2 and 3) located on Point of Shoals and two stations (1 and 4) located in the relict channel. The locations where buoys marked the sampling stations established by Team 2 are shown in Figure 22. Stations 1, 2, 3, and 4 were monitored hourly during daylight. Team 2 followed similar procedures for obtaining water samples as did Team 1. The instrument cage with the attached transmissometer was manually lowered off the side of the boat, and transmissivity measurements were taken at 1-ft intervals.

28. The two automatic samplers were deployed to obtain water samples throughout the night after boat-deployed data collection activities were completed. One sampler was located approximately 900 ft due east of the discharge point on Point of Shoals (Station 2.5). The second sampler was located approximately 600 ft northeast of the discharge point (Station 4.5). The locations of both water samplers are shown in Figure 22. The samplers were programmed to take composite sub-samples through time. Four 200-mℓ samples were taken per bottle during a 6-hr time period. The sampler at Station 4.5 was overturned by the discharge pipeline on 30 September and was not

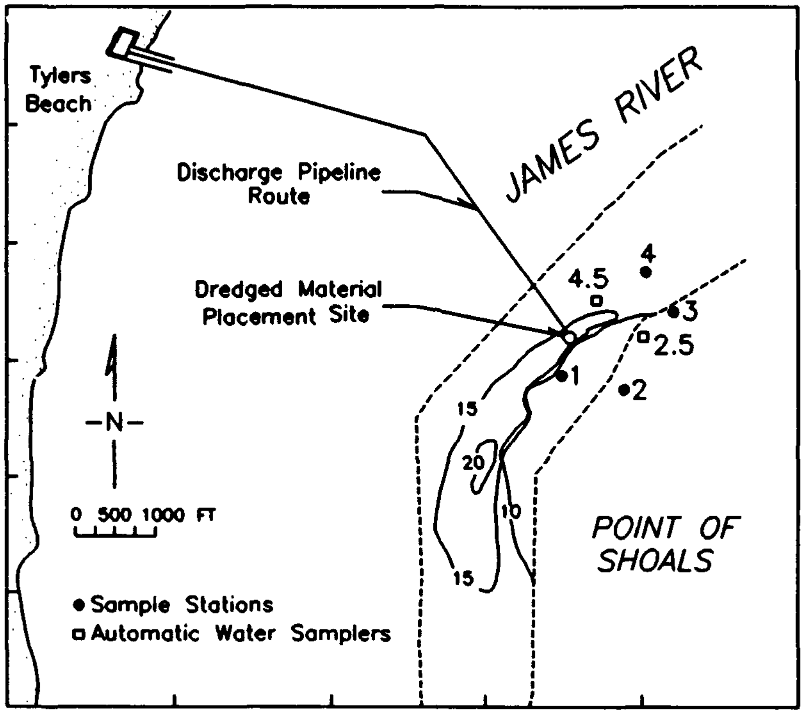

Figure 22. Location map for Team-2 sample stations

operating properly again until the morning of 2 October. Because of predicted bad weather for 3 October, this sampler was reprogrammed to take discrete samples at 30-min intervals to obtain a maximum number of samples throughout the day. Both automatic samplers were removed at 1600 EDT on 2 October. From 30 September to 3 October, water surface elevations, in addition to temperature and conductivity measurements, were recorded in 15-min intervals by a CTD recorder located at the Rescue Marina on Jones Creek, Virginia, approximately 4 miles south of the project site.

29. During dredging operations, which began 1 October, Team 1 initially monitored the project area to detect the direction and extent of the sediment plume (which was not visible on the water surface) along the center of the relict channel (north to south). Then, a series of 1,500-ft-long acoustic transects were run across the channel at 200-ft intervals in an "S" pattern running approximately east to west, then west to east, to determine the lateral extent of the plume. Figure 21 is a schematic showing both the background and placement monitoring transects. Once the plume and its extent had been determined, water samples and CTD profiles were taken at stations at and around the discharge point where the plume had been detected and background conditions had been sampled (see

Figure 14). The short cross-surveys and sampling procedure were then repeated as the tide reversed to obtain data during different phases of the tidal cycle. At times the *Lynnhaven* had to break from planned transects to avoid traffic in the river channel or to go around the discharge pipeline. During periods of ebb tide, when shallowness of the water on Point of Shoals would not permit access by the *Lynnhaven*, samples were taken as close to the original stations as possible. Bottom grab samples were taken at nine stations during monitoring operations on 2 October (see Figure 17). Team 2 followed procedures for monitoring placement operations similar to those followed during background monitoring.

30. Because the response of the transmissometer and the acoustic instrumentation depends on particle size distribution, suspended material type, and total concentration, calibration procedures were performed in the field. On 3 October, water samples were obtained for the purpose of calibration. The transmissometer from Team 2 was taken aboard the *Lynnhaven*, and the water sampling tube was attached. The field calibration procedure consisted of collecting water samples and transmissometer readings at two different depths within the acoustic beam. This procedure was repeated a number of times to cover a wide range of sediment concentrations. An additional field calibration of the transmissometer was carried out using a set of water samples taken from monitoring activities at Station 4.

31. The water samples were analyzed in the laboratory to determine the suspended material concentration. With these concentrations, empirical calibration curves were produced from which suspended material concentration can be obtained from sound and light intensity measurements taken in the field during the TBMP. One additional survey was run on 3 October after completion of the field calibration; however, dredging operations had temporarily ceased, and no material placement occurred during the survey.

Laboratory Analysis Procedures

Salinity

32. Salinity measurements from individual samples taken by both monitoring teams were evaluated with an AGE Instruments, Incorporated, Model 2100 MINISAL salinometer with temperature compensation. The salinometer is a fully automated system calibrated with standard seawater, and it has a manufacturer's rated accuracy of ± 0.003 ppt on samples ranging from 2-42 ppt.

Suspended material

33. Suspended material concentration values were obtained from individual water samples by filtration of 100 mℓ from each sample using Nuclepore (Registered Trademark) 0.45-μm polycarbonate filters. The samples were first desiccated and preweighed; then the sample was drawn through the filter by a vacuum system (8-lb vacuum maximum). Afterwards, the filters and holders were washed with distilled water, and the filters were dried for 1 hr at 105 °C and reweighed. The suspended material concentration for each sample was calculated from the weight of dried material retained on the filter.

Bottom sediment

34. Sediment size determinations from bottom grab samples taken during the TBMP were made using a Particle Data, Incorporated, ELZONE 80XY particle sizer which electronically measures the displacement of particles as they pass through a 0.094-mm-diam orifice and then resolves them into discrete size classes. Approximately 1 mℓ from each sample was wet sieved through a No. 200 screen to remove particles greater than 0.074-mm diameter. The sieved samples were then dispersed by mixing with equal volumes of 4-percent Calgon solution and disaggregated by ultrasonification for at least 10 min. The subsamples (approximately 1 mℓ) were then mixed with 100 mℓ of 1-percent-NaCl electrolyte for analysis. This analytic method generally followed the manufacturer's recommendations and is standard.

35. Moisture content was determined by drying a pre-weighed subsample and reweighing. Moisture content is defined as the weight of water divided by the weight of solids in a sample, and can be converted to related measures such as solids content and bulk wet density.

36. Tests were performed to determine the settling characteristics of the material, because fine-grained sediment particles tend to flocculate and their settling is not necessarily related to individual grain size. The settling tests were conducted in a clear acrylic tube with a 10-cm diameter and a height of 1.85 m. Site water was mixed with various amounts of dredged material for 5 min and poured into the settling tube. A sample was immediately drawn from near the bottom of the tube after settling periods of 5, 10, 20, 30, 45, 60, 90, 120, 180, and 240 min. Care was taken to keep test suspensions and equipment at a constant temperature during testing. Test samples were analyzed for total suspended material using the same procedure as outlined in paragraph 33. Results were analyzed by assuming that the fraction of material removed at a certain time had a settling speed equal to the height from the sampling point to the free surface of the suspension divided by the elapsed time for settling.

37. An additional test was performed to measure settling at high concentrations representative of the underflow created at the placement site. The objective was to characterize the hindered-settling consolidation of the slurried dredged material. The sample tested was collected 1 ft off the bottom near the placement site and had a concentration of 15.7 g/ℓ. The sample was shaken and poured into a 100-mℓ graduated cylinder. The suspension was in the hindered-settling concentration range, sometimes referred to as zone settling, where the suspension settles as a mass and a clear layer of fluid forms above the suspension (Teeter 1986). The descent of the interface between the suspension and the supernate which formed above the suspension was observed for 24 hr. The initial descent rate over the first 6 min was equivalent to the settling speed at the initial concentration. The suspension height and average concentration at longer times was representative of the effects of hindered-settling consolidation on suspensions of similar height and sediment composition in the field.

Transmissometer calibration

38. In addition to the field calibration discussed in paragraph 30, a laboratory calibration of the transmissometer used during the TBMP was conducted. The transmissometer was calibrated to make high-resolution vertical profiles of suspended material concentration and ensure that in situ water samples captured vertical suspension features. Transmittance was converted to a beam attenuation coefficient (per meter) which is linearly related to concentration for a given suspended material. In the laboratory, the transmissometer was placed into an insulated calibration chamber. Site water was poured into the chamber and allowed to equilibrate to room temperature. A small recirculation pump kept the test chamber mixture homogeneous. Once the output from the transmissometer settled to a constant value, a background transmissometer reading and water sample were taken. A measured volume of dredged material sample taken from a leak in the dredge pipeline was added to the test chamber, and a transmissometer reading and water sample were taken. This process was repeated until points were collected over the entire range of the transmissometer output. The water samples taken during the calibration were analyzed for suspended material concentration and were used to calculate a calibration curve for the transmissometer. The transmissometer readings taken in the field were then converted to concentration values.

Acoustic instrument calibration

39. The general relationship between acoustic backscatter strength and the concentration, composition, and size distribution of suspended sediments is being investigated as part of the development of the PLUMES acoustic instrumentation. It is possible to relate acoustic backscatter strength to suspended material concentration if the composition and particle size distribution of the

material are known. This is achieved by calibrating the backscatter measurements against the concentrations of suspended material in the same water volume ensonified by the acoustic beams. Two calibrations for the acoustic instruments used during the TBMP were carried out, one in the field (see paragraph 30), and the other at the DRP calibration facility located at the offices of RD Flow in San Diego, CA.

40. Procedures and equipment to calibrate acoustic sensors to determine particulate concentration are in a developmental stage, and only a limited number of calibration studies have been performed (Young et al. 1982; Schaafsma and der Kinderen 1985; Tamura and Hanes 1986; Thorne et al. 1991). An extensive calibration project for the PLUMES was under way during the analysis stage of the TBMP, and knowledge gained was applied to obtain acoustic-based estimates of concentration. The laboratory calibration was done by measuring the backscatter strength on known, artificially produced concentrations of material obtained from a bottom grab sample taken at the project site. The first step in the calibration was to remove the moisture from the material by placing the sample in an oven. The sediment was then allowed to cool in a chamber filled with desiccant to prevent moisture from condensing in the dried material. Samples weighing 2, 5, 10, 20, 50, 100, 200, and 400 g were additively dissolved in a 370-ℓ acoustic calibration tank. Before the samples were added to the tank, they were thoroughly dissolved in water using a blender and then degassed with a vacuum pump. For each concentration, backscatter measurements were made with the 2.4-MHz system using the same configuration (i.e., pulse length, resolution, etc.) employed during the field surveys. These measurements were then corrected for transmission loss to produce a calibration curve similar to that obtained from the field calibration.

PART III: RESULTS[1]

41. This chapter describes the data analysis and results of the project. Appendix B contains tables listing temperature, salinity, current speed and direction, and suspended sediment concentration values measured during both background and plume monitoring.

Water Temperature

42. Water temperature was recorded by two methods. Team 1 took CTD profiles at selected stations in the vicinity of the discharge point before and during dredged material placement. Another CTD recorder was located at Rescue Marina, on Jones Creek, Virginia, approximately 4 miles south of the project site. This sensor took measurements in 15-min intervals from 30 September to 3 October.

Project site

43. Over the course of the project, water temperature ranged between 21.1 and 22.8 °C throughout the water column, with a vertical variation of less than 1.0 °C. No significant temperature variation was observed to result from dredging and placement operations. A complete list of information obtained from the CTD records, including temperature, salinity, and depth at the project site is given in Table B1.

Rescue Marina

44. The temperatures measured at Rescue Marina are given in Table B2. The maximum water temperature measured by the CTD recorder at this location was 24.9 °C, taken at 1915 EDT on 29 September. This was the first measurement taken after deployment of the device. If this measurement is eliminated, the temperature ranged from 19.9 to 23.1 °C.

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[1]Written by Ms. Michelle M. Thevenot, Messrs. Ramon G. Cabrera and Allen M. Teeter, Ms. Terri L. Prickett, and Mr. Craig A. Huta.

Salinity

45. Six independent measurements of salinity were obtained. Team 1 took water samples that were analyzed for salinity in the laboratory and CTD measurements of which conductivity and temperature were converted into salinity values. Team 2 obtained salinity measurements from pump-out water samples taken at four stations (Figure 22) and automatic water samples taken at two stations (Figure 22) that were analyzed for salinity in the laboratory. In addition, a portable salinometer measured salinity at the project site, and salinity was measured with a CTD recorder at Rescue Marina.

Team-1 project site samples

46. Figures 23 and 24 are time series of salinity taken from water samples collected at three different depths during background and plume surveys on 30 September and 1 October, respectively. Figure 23 shows that the time variation of salinity followed the tidal cycle, with minima in salinity occurring during slack water and maxima occurring at high tide. Figure 24

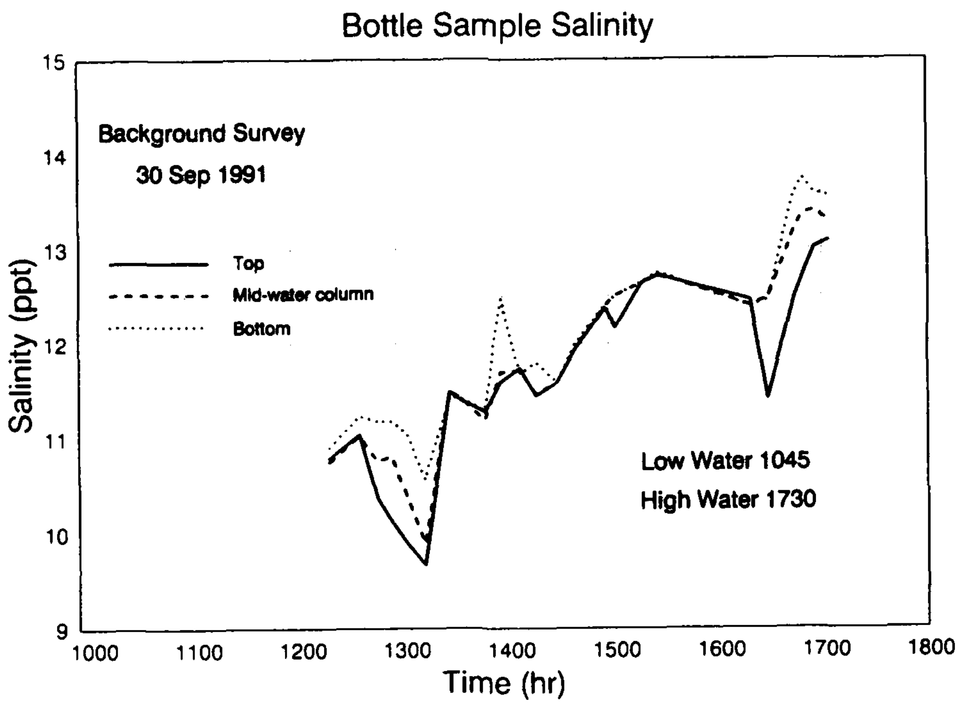

Figure 23. Time series of salinity (30 September)

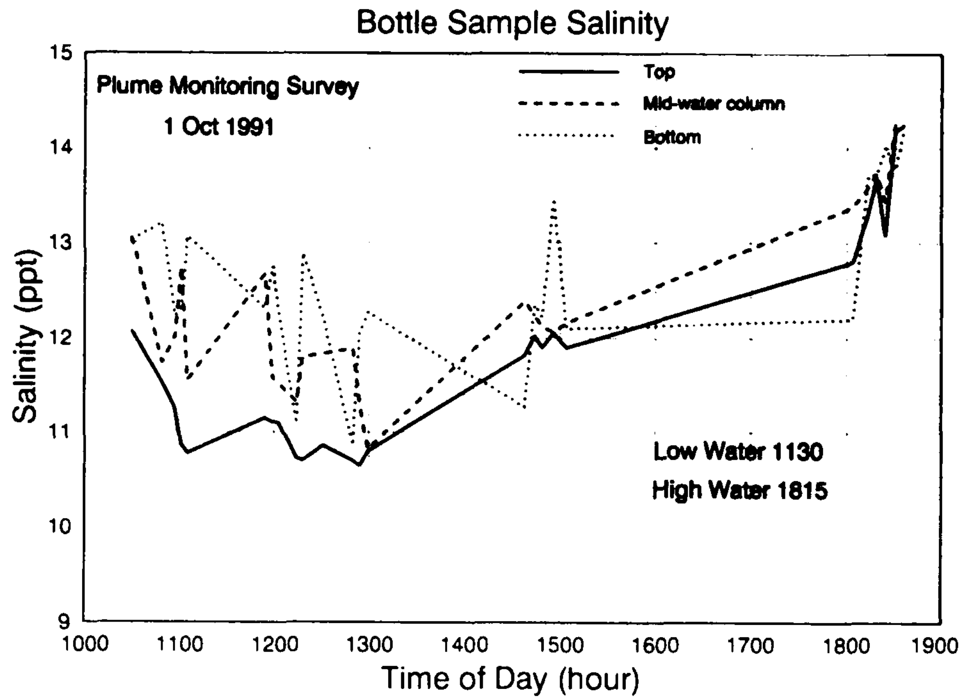

Figure 24. Time series of salinity (1 October)

shows an increase in salinity with depth of as much as 2 ppt during low tide. The salinity based on these samples ranged from 9.7 to 14.3 ppt. Salinity measurements obtained by analyzing samples taken by Team 1 are listed in Table B3.

CTD recorder at the project site

47. Field salinity from CTD measurements taken by Team 1 varied between 9.7 and 14.3 ppt. Points of low salinity taken on 29 September were eliminated from analysis because comparison with water sample data showed that they were spurious. As with the water samples, the salinity varied with the tidal fluctuations. Figure 25 is a scatter plot showing the range and variability of field salinity measurements taken during background and plume monitoring. A trend of increasing salinity of approximately 1 ppt with the occurrence of dredging is indicated in Figure 25.

Team-2 project site samples

48. The project site samples taken by Team 2 were used for verification of salinometer measurements and are not discussed in detail. These measurements are listed in Table B4.

Salinometer

49. Throughout the project, salinometer measurements taken by Team 2 varied between 10.0 and 13.5 ppt at the four stations, falling within the range of salinity measurements obtained by Team 1. The time variation of salinity taken at the four stations showed minima occurred at low tide. No significant change in salinity was discerned as a result of dredging and placement operations.

50. Vertical profiles of salinity at Station 4 were examined in detail. The profiles exhibited linear gradients and could be divided into two groups, those with surface to bottom differences greater than 1.0 ppt and those with differences less than 0.6 ppt. There were an equal number of both occurrences. The average surface-to-bottom salinity difference was 1.3 ppt for the first group and 0.2 ppt for the second group. Salinity differences were converted to vertical density gradients by using the measured temperatures and salinities. The density value at the top of the water column was subtracted from the value at the bottom and the difference divided by depth. The calculated density gradients were 0.234 and 0.038 $kg/m^3/m$, respectively, for the two groups. These density gradients were used in evaluating plume dynamics.

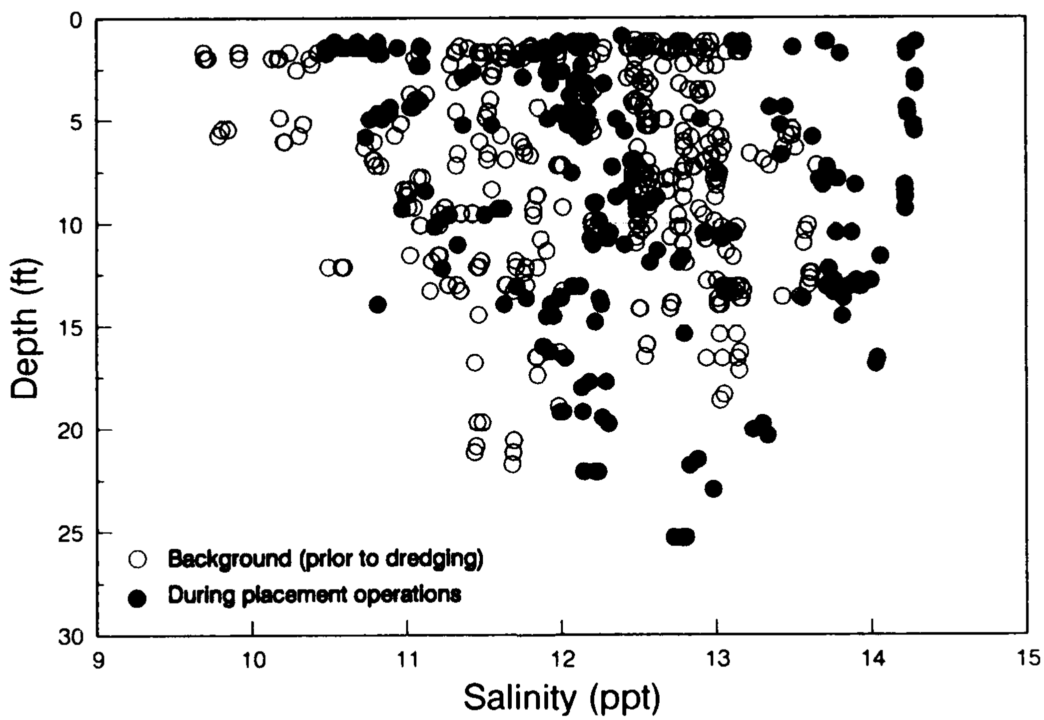

Figure 25. Range of salinity near the project site

Automatic water samples

51. The salinity measured at the two automatic water samplers located at Stations 2.5 and 4.5 (see Figure 22) ranged from 11.6 to 14.6 ppt. At Station 2.5, composite samples taken from 30 September to 2 October show that the salinity varied with the tidal flow, with maxima occurring near high tide and minima at slack water. Discrete samples were taken at Station 4.5 on 2 October. These samples showed the same fluctuations with tidal flow as at Station 2.5. In both cases, the salinities during background monitoring were similar to those obtained during dredging. Salinity information obtained from the automatic water samples is listed in Table B5.

CTD recorder at Rescue Marina

52. The CTD recorder at Rescue Marina established to take measurements of tidal fluctuations showed higher salinity values than at the project site. The salinity data obtained at this location are listed in Table B2 and varied from 13.3 to 16.4 ppt. Because measurements were taken at the same location as the tide gage and at 15-min intervals, the variation in salinity with the tidal cycle is readily observed. Minima in salinity corresponded to low tide, and maxima occurred during high tide. No change in salinity can be attributed to dredging and placement operations.

Comparison of salinity measurements

53. Because the CTD measurements taken at the project site showed an increase in salinity with the onset of placement operations (see Figure 25), these measurements were compared to the CTD measurements taken at Rescue Marina. The salinity at Rescue Marina would not be expected to fluctuate due to the discharge of material because it is located 4 miles from the project site. These two sets of data were compared statistically and a summary of that analysis is shown in Table 4. The coefficient of variation is the standard deviation divided by the mean, quartiles are the 25- and 75- percentile values, and outliers were defined as any point further than two standard deviations from the nearest quartile. The statistical data showed that the increase in salinity at the project site during the two periods was less than the increase at an independent site. The other measures of salinity did not show significant changes in salinity after the initiation of dredging.

Bed Sediments

54. Bottom grab samples were taken at various stations in the vicinity of the discharge site (see Figure 17). The samples were analyzed in the laboratory for particle size distribution and moisture content as well as for settling characteristics. The results of these tests are given in the following paragraphs.

Table 4

Statistical Summary of CTD Recorded Salinity

Location	No. Samples	Mean ppt	Coefficient of Variation	Median ppt	Quartiles ppt	Outliers ppt
			Pre-Dredging			
Rescue Marina	115	15.37	0.03	15.4	15.0 15.6	None
Project Site	110	12.20	0.07	12.5	11.6 12.9	9.7
			Dredging			
Rescue Marina	267	15.59	0.02	15.5	15.3 15.8	13.3
Project Site	72	12.28	0.09	12.1	11.5 13.1	None

Particle size distribution and moisture content

55. Bed and dredged material samples were generally found to be predominantly fine-grained. A few bed samples consisted predominantly of shell fragments and were not analyzed. Appendix C contains the results of grain size and sediment analysis of individual samples. Plate C25 in Appendix C summarizes the analysis of a sample of dredged material taken directly from the discharge line. The plates in Appendix C contain cumulative and differential frequency plots, summary distribution statistics (mean, sorting, and skewness), percent retained on the 0.074-mm sieve, and moisture content expressed as a percent. Both millimeter and phi size scales are used, where phi is the negative log-base-2 of the diameter (mm).

56. Mean phi size contours of 13 samples collected before dredging are plotted in Figure 26. The corresponding results for samples collected 2 days after dredging started are shown in Figure 27. The average moisture content for 12 pre-dredging bed samples was 172 percent, corresponding to 480,000 mg/ℓ solids content. The average moisture content of the 10 samples taken during dredging was 180 percent. This corresponds to a solids content of approximately 500,000 mg/ℓ.

57. Because the size gradation difference between the dredged material and bottom sediments from near the disposal site was slight and the number of samples relatively small, size gradation data cannot be used to distinguish placed dredged material from other material existing at and transported to the site.

Laboratory settling

58. Column settling tests were performed at 1440-, 296-, 148-, and 80-mg/ℓ starting concentrations. In the lowest concentration test, only 35 percent of the material settled during the 4-hr test interval. The settling curve was extrapolated to 50 percent to estimate the median

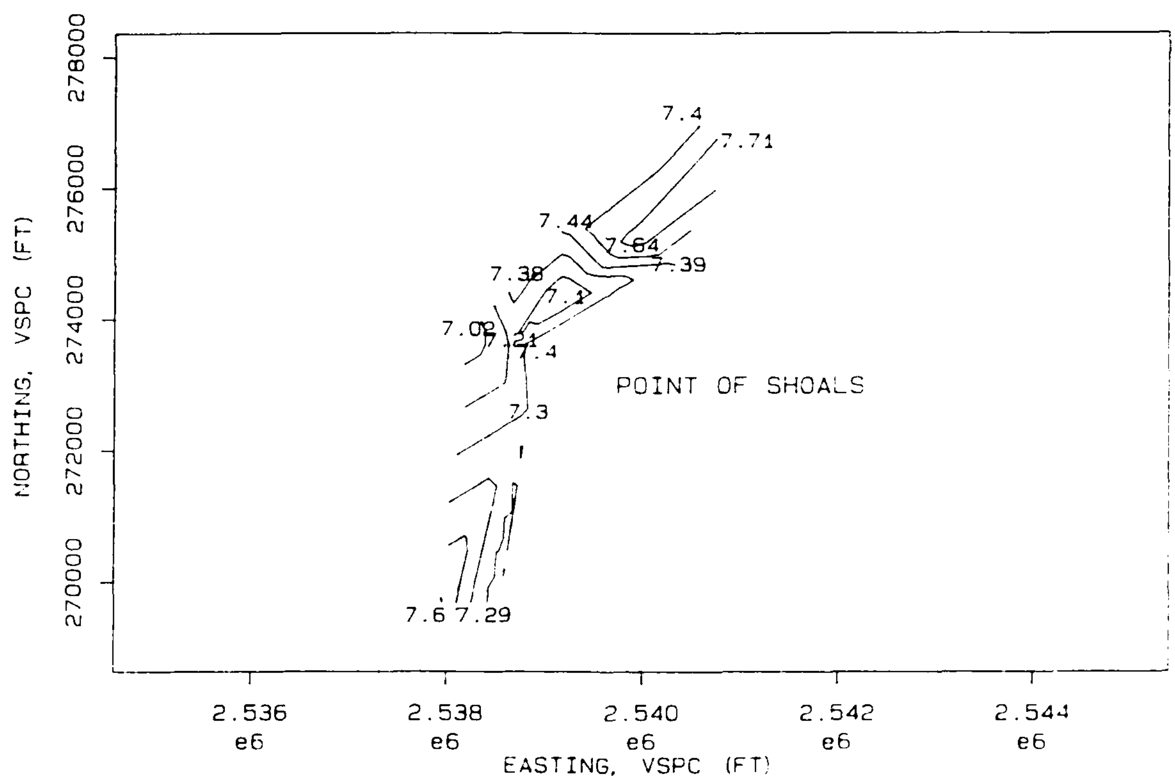

Figure 26. Pre-dredging sediment mean phi size contours

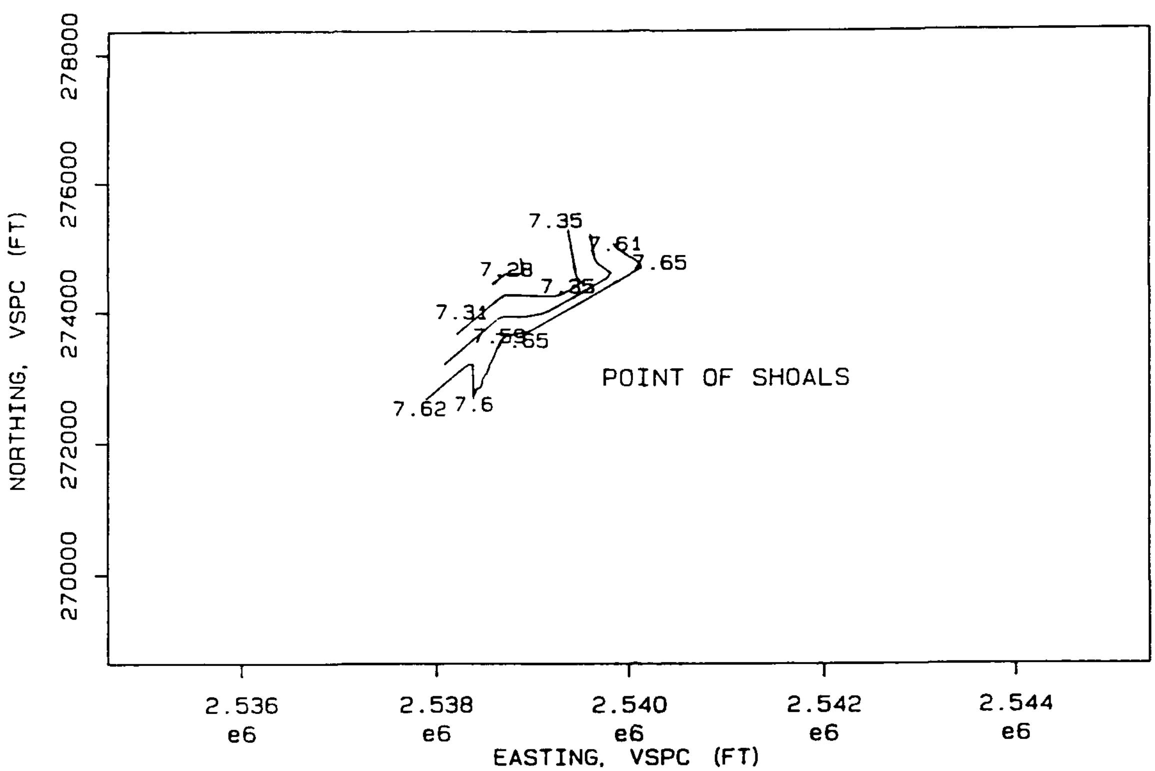

Figure 27. Mean phi size contours of sediments collected during dredging operations

settling speed for this test. For the other tests, the medians were interpolated from the settling curves. The median settling speed for the four tests is plotted in Figure 28. The median settling speed did not level off in the lower concentration tests. Based on experience, the lowest concentration is probably near the low-settling plateau normally exhibited by cohesive suspensions.

59. Settling speeds of fine-grained estuarine sediments generally vary with concentration and are constant at low concentration (below about 100 mg/ℓ). At higher concentrations, settling speeds for fine-grained material are enhanced and can be expressed as a power law with a slope of 1.3. Enhanced settling occurs in the range of concentrations up to approximately 50,000 mg/ℓ, depending on the specific sediment. At higher concentrations settling is hindered by inter-particle contact and restricted pore space.

60. An additional test performed at 15,700 mg/ℓ indicated settling speed at this concentration was 0.20 mm/sec. This concentration, when compared to the values presented in Figure 28, showed a hindered settling speed. Therefore, the settling concentration range at which inter-particle contact and restricted pore space begin to dominate is located at

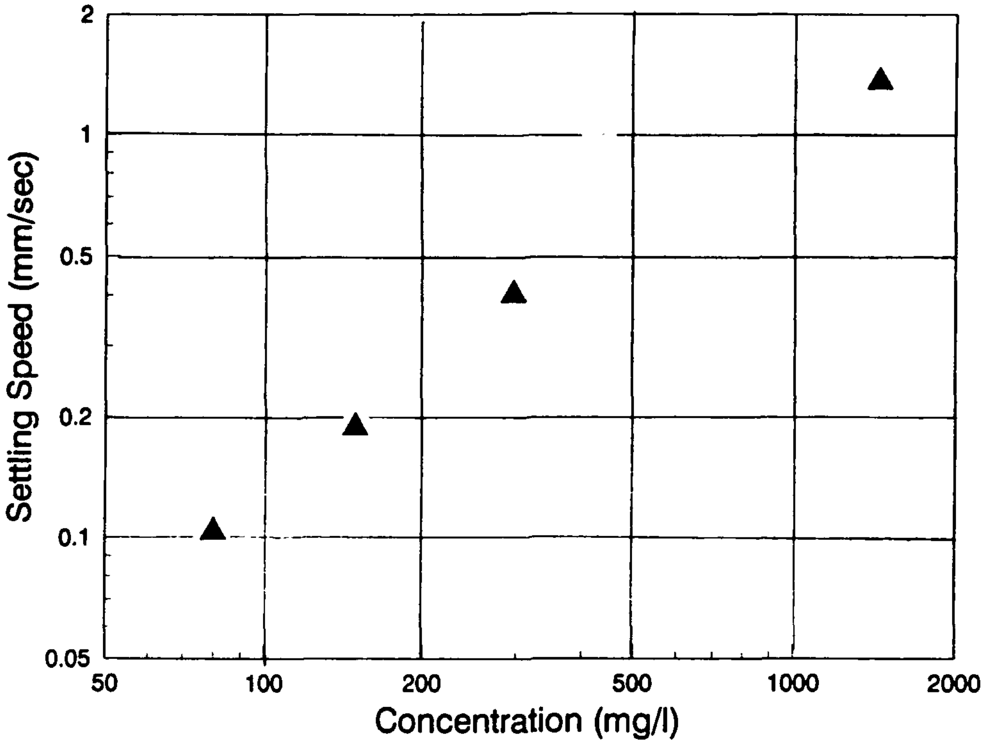

Figure 28. Median settling speeds from column settling tests

approximately 10,000 mg/ℓ for the Tylers Beach dredged sediment. As the sediment settled, suspension height in the test column decreased, and the average concentration increased. The average suspension increased in concentration from 15,700 to 52,000 mg/ℓ in the first 15 min of the test as the suspension consolidated by hindered settling. The concentration increased to 79,000 mg/ℓ in the first hour.

Current Measurements

61. Two methods of measuring currents were used during the TBMP. A propeller velocity meter was cast over the side of the *WES-10* from which both current magnitude and direction could be ascertained. In addition, a BBADCP, which has proven to be an accurate velocity meter, took 3-D current velocity measurements in the water column. Because the currents in this area are predominantly tidal generated, information obtained from the tide gage located at Rescue Marina is also discussed in this section.

Tide data

62. From 30 September to 3 October, regional water surface elevations were recorded with a sensor located at Rescue Marina. Water elevation measurements were taken in 15-min intervals, and ranged from 4.8 to 7.7 ft mlw, with a mean water elevation of approximately 6.2 ft mlw. The datum mlw is defined to be 1.17 ft below NGVD, 1972 adjustment, at the project site by the National Ocean Service. Low tide occurred at 1045 EDT on 30 September, 1130 on 1 October, and 1245 on 2 October. High tide occurred at 1730 on 29 September, 1815 on 1 October, and 1915 on 2 October. The measured tide at Rescue Marina is plotted in Figure 29.

Propeller velocity meter

63. Current velocities were measured hourly during daylight from 30 September to 3 October at Stations 1, 2, 3, and 4 (Figure 22). During this time the current speed ranged from 0.1 to 2.0 ft/sec. The current typically flowed to the northeast during flood tide and to the southwest during ebb tide. In some instances, however, bottom measurements of current direction indicated a shear, with the bottom current directed approximately opposite of the surface current direction. This occurrence was noted, in particular, at Station 4 on 2 October for most profile surveys taken during that day. Table B4 gives current speed and direction measurements from the propeller velocity meter.

64. During periods of peak ebb tide, the maximum current speed at Station 1 ranged from 0.8 to 1.3 ft/sec. In periods of current reversal (i.e., slack water), minimum absolute current speed was 0.3 ft/sec. Information for peak flood tide was not obtained because peak flood tide did not occur during the monitoring period. The minimum measured speeds were lower during dredging (0.3 ft/sec) as compared to background measurements (0.6 ft/sec) at Station 1. The low current speed would tend to decrease the amount of material transported from the placement site; however, the decreased current speed observed during dredging may simply be attributable to less data taken during background sampling at this station.

65. At Station 2, the maximum current speed during peak ebb tide was 1.1 ft/sec. The maximum current speed recorded during flood tide was 1.2 ft/sec. As at Station 1, the minimum current speed was less during dredging (0.1 ft/sec) than during background monitoring (0.5 ft/sec).

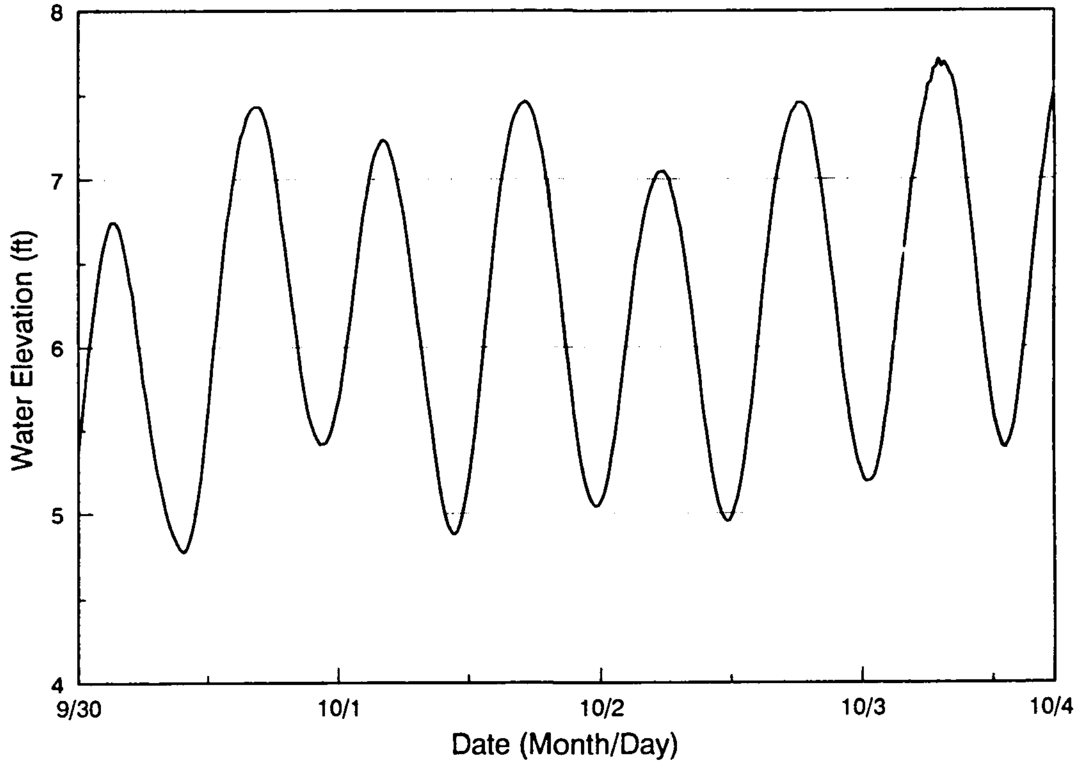

Figure 29. Water elevation at Rescue Marina

66. Station 3 exhibited a higher speed range (1.5 to 2.0 ft/sec) at peak ebb tide than Stations 1 and 2. At Station 3, the minimum current speed during background measurements was 1.0 ft/sec. This speed is much higher than during dredging when the minimum was 0.3 ft/sec. However, the maximum at this station was lower during background than during dredging. The maximum current at Station 3 increased from 1.6 ft/sec during background measurements to 2.0 ft/sec during dredging. The maximum current speed occurred during peak ebb tide on both 1 and 2 October, whereas no measurements were taken during peak ebb tide during background monitoring (30 September).

67. At Station 4, the current speed ranged from 0.1 to 1.8 ft/sec. Similar to Station 3, Station 4 exhibited a smaller range in current speed before dredging than during dredging. The current record at Station 4 was examined more closely than at the other stations because this station had a depth similar to the placement site (approximately 25 ft MLW), and the current is likely to be representative of that at the placement site. Two characterizations of the current were developed. The frequency distribution of mid-depth current speed at Station 4 was compiled to represent depth-averaged conditions at the discharge point. Current-speed

observations were divided into four classes shown in Table 5. The average current speed was 0.86 ft/sec for 21 observations.

Table 5

Frequency of Current Ranges

Current Speed, ft/sec	Frequency, Percent
0.0 - 0.5	19
0.5 - 1.0	57
1.0 - 1.5	19
1.5 - 2.0	5

68. Another characterization of the current compiled from Station 4 was the mean ebb and flood flow speeds at each depth found in Table 6. These data indicate conditions typical of an estuarine site. Gravitational estuarine circulation is present at Station 4 and probably indicative of conditions at the placement site. The surface currents are ebb dominated, whereas the bottom currents are somewhat flood dominated; the depth-averaged flow is seaward, as expected for the river.

Table 6

Mean Current Speed, ft/sec

Depth, ft	Flood Tide	Ebb Tide
Surface	0.82	1.30
Middepth	0.91	0.78
Bottom	0.73	0.51
Depth avg.	0.82	0.86

BBADCP current measurements

69. Vertical profiles of the horizontal current flow measured with the 2.4-MHz acoustic system showed that the current in the James River was dominated by tidal flow. The current was generally directed to the northeast during flood tide and to the southwest during ebb tide, and roughly aligned along the channel. Current speed varied from 0.0 ft/sec during slack water (which occurred during current reversal) to a maximum of 1.6 ft/sec. Measurements varied spatially and were not repeated hourly at each station as were the propeller current measurements. The current velocities measured using the 2.4-MHz BBADCP are listed in Table B3 of Appendix B.

70. Background. On 30 September, peak flood tide occurred at approximately 1645, and the current speed ranged from 1.4 ft/sec at the surface to 1.0 ft/sec at the bottom of the water column. The absolute maximum speed measured on 30 September was 1.6 ft/sec, when the speed was not great throughout the water column. The current profile containing the absolute maximum velocity shows a significant current shear, with the bottom current of 0.5 ft/sec directed approximately opposite to the surface current. On 30 September, several current profiles were found to show a shear. These shear events took place in the afternoon and are attributable to winds from the northeast with speeds as great as 12 mph as measured on the *Lynnhaven*.

71. During dredging. On 1 October, the measured peak ebb tide at the site occurred at approximately 1130 EDT. The current varied from 1.2 ft/sec at the surface to 0.8 ft/sec at the bottom of the water column during maximum ebb flow. Slack water occurred at approximately 1300, with a minimum current speed of 0.1 ft/sec. During higher flood flows, a typical vertical current profile through the water column ranged from 1.0 ft/sec at the surface to 0.7 ft/sec at the bed. Current speeds were higher during background monitoring (maximum 1.6 ft/sec) than during dredging (maximum 1.2 ft/sec).

Suspended Material Concentration

72. Five independent measurements of suspended material concentration were obtained during the TBMP. Three of these measurements consisted of individual water sampling by Team 1, Team 2, and the automatic water sampler. The water samples were analyzed in the laboratory for suspended material concentration. In addition, sound and light intensity

measurements were taken with a BBADCP and a transmissometer, respectively. These two indirect measurements can be converted to suspended material concentration through calibration procedures.

Team-1 samples

73. Background monitoring. Samples taken by Team 1 during background monitoring indicate a wide range in suspended material concentration, particularly near the bottom of the channel (Table B3). Figure 30 is a time series of suspended material concentration at three different depths on 30 September. Background measurements taken on 29 September, and listed in Table B3, are not discussed due to lack of current and tidal data on this date. It should be noted, however, that suspended material concentration ranged from 8 to 67 mg/ℓ, with no unusual observations to report. On 30 September, concentrations from surface and mid-water column samples ranged from a minimum of 8 mg/ℓ during slack water to a maximum of 53 mg/ℓ during moderate to high current speed (0.6 to 1.2 ft/sec). Suspended material concentration near the bottom showed greater variability, ranging from 23 mg/ℓ to a maximum concentration of 115 mg/ℓ. The maximum concentration was observed on 30 September at Station 6 during flood tide with a mid-depth current speed of 1.2 ft/sec. Several near-bottom samples taken just before and after this sample at Stations 1, 4, 8, 10, and 13 (see Figure 14) also had higher concentrations, ranging from 57 to 98 mg/ℓ, with corresponding current speeds of 0.5 to 1.3 ft/sec.

74. During dredging. The maximum background suspended material concentration measured by Team 1 was 115 mg/ℓ. Therefore, in this report, concentrations less than this value are considered representative of normal conditions. Surface and mid-water column samples taken by Team 1 during dredging and placement operations on 1 and 2 October ranged from 6 to 57 mg/ℓ, similar to concentrations from background samples. As shown on Figure 31, six near-bottom samples (one near-bottom concentration value at 1030 EDT representing a concentration greater than 4,000 mg/ℓ was repeated and is counted twice) taken on 1 October yielded suspended material concentrations that exceeded this threshold. On 1 October, at the discharge point (Station 32; see Figure 14), high concentrations were observed in a near-bottom sample collected at a depth of approximately 21 ft. Within a 5-min time period, sampling was repeated at the same location. These two samples yielded concentrations of 15,702 and 4,168 mg/ℓ. The current profile measured during the time ranged from 0.3 ft/sec near the bottom to 1.2 ft/sec near the water surface. Surface and mid-column samples taken with these near-bottom samples had

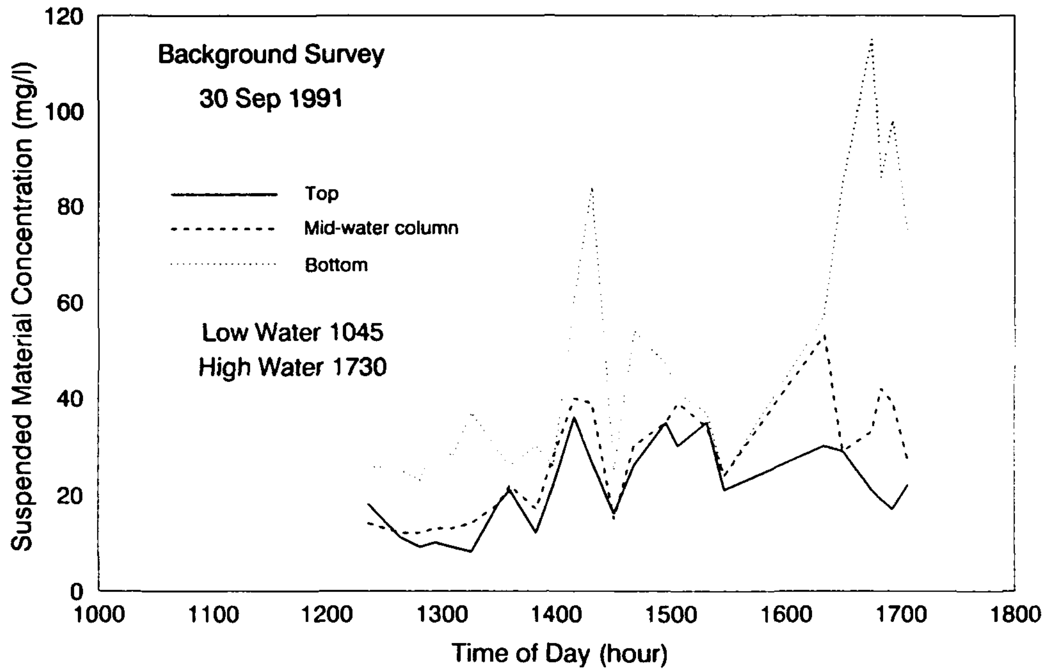

Figure 30. Time series of suspended material concentration (30 September)

considerably lower concentrations, 21 and 30 mg/ℓ, respectively. Near-bottom samples from Station 21, located on the edge of Point of Shoals and downstream of the discharge point, also contained high concentrations of 11,071 mg/ℓ during ebb tide (23-ft depth), and 4,846 mg/ℓ during tide reversal from ebb to flood (26-ft depth). Surface and mid-column concentrations for both sample profiles were within typical ranges, varying from 14 to 29 mg/ℓ, similar to concentrations at that station during background monitoring. A near-bottom sample at Station 31.5, located approximately 250 ft downstream of the discharge point, taken during ebb tide (mid-depth current of speed 0.6 ft/sec), yielded a concentration of 273 mg/ℓ. The corresponding surface and mid-column sample concentrations were 22 and 24 mg/ℓ, respectively. Late in the afternoon of 1 October, the dredge ceased operation for approximately 40 min. A near-bottom sample obtained from Station 9, located approximately 750 ft northwest of the discharge point and toward the shore, had a concentration of 173 mg/ℓ.

75. All six of the 97 samples identified as having high concentrations in the preceding paragraph were from near-bottom samples obtained at stations located at or relatively close to the point of discharge. Those samples were also taken during periods of moderate to high current

speed (0.6 to 0.9 ft/sec). Although these measurements conceivably may represent concentrations of suspended dredged material near the bottom of the placement site, the measurements are suspect because of potential resuspension of bottom material induced by attempts to lower the measurement apparatus to within 1 ft of the bottom in a current. Team 2 took measurements 2 ft above the bottom, making it less probable for the sampler to suspend bottom material, and obtained a maximum concentration of 108 mg/ℓ during dredging operations. Samples taken on 2 October by Team 1 had concentrations similar to background levels.

Team-2 samples

76. Team 2 took samples from a pump-out system that was lowered over the side of the *WES-10*. Stations 1, 2, 3, and 4 (Figure 22) were monitored hourly during daylight, at which time samples were taken 2 ft from the surface, mid-depth in the water column, and 2 ft from the channel bed. The samples were analyzed in the laboratory for suspended material concentration.

77. Background monitoring. During background monitoring on 30 September, an increase in concentration throughout the water column was observed at Stations 1 and 4 (see Figure 22)

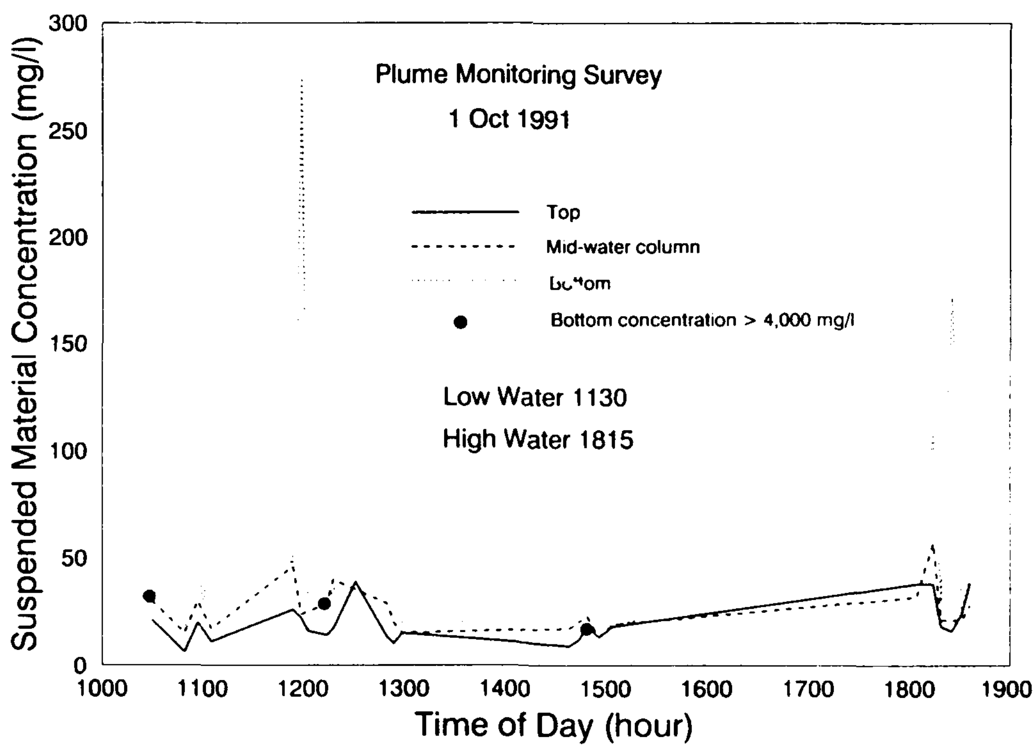

Figure 31. Time series of suspended material concentration (1 October)

monitored by Team 2 at 1600 to 1630 EDT during a period of high wind speed (approximately 10 mph) and flood tide. A higher concentration was noted during this period at Station 1, in particular, located southwest of the discharge point in the relict channel. Prior to 1600, concentration at Station 1 ranged from 19 to 47 mg/ℓ. The Station 1 vertical profile measurement made at approximately 1600 had concentrations of 85, 99, and 102 mg/ℓ at the top, mid-water column, and near-bottom depths, respectively. At Station 4, the suspended material concentration, ranging from 25 to 46 mg/ℓ before this higher wind-speed event, increased to a range of 51 to 57 mg/ℓ measured at 1630.

78. During dredging. On 1 and 2 October, during dredging operations, concentrations from samples taken by Team 2 at Stations 1, 2, and 3 ranged from 6 to 27 mg/ℓ. At Station 4, however, surface and mid-water column concentrations obtained in the morning (ranging from 5 to 24 mg/ℓ) increased to a range of 31 to 58 mg/ℓ late in the afternoon for both days. Near-bottom concentrations at Station 4 also increased on both afternoons, but were higher than at the surface and mid-depth. The morning near-bottom concentration ranged from 14 to 55 mg/ℓ, whereas the afternoon concentration range was 68 to 108 mg/ℓ. At this station, the suspended material concentration increased with the onset of flood tide, which occurred shortly after the discontinuation of monitoring on each day.

79. Comparison of background and during-dredging concentration measurements. Suspended material concentrations obtained by Team 2 were compiled from the pre-dredging and dredging periods to identify dredging effects. A statistical summary for these two periods is given in Table 7 (see paragraph 53 for a description of the variables given in this table). Suspended material concentration was appreciably higher during the pre-dredging period. Wind speed was highest during the pre-dredging period and the higher concentrations are believed to be associated with the higher winds.

80. Suspended material concentrations from pre-dredging and dredging periods can be compared by examining their statistical distributions. This was done graphically by constructing probability plots (Figures 32-34). Sample values were arranged in order of magnitude using their position in units of the standard deviation (or standard normal) relative to the mean as one coordinate. The other coordinate was the suspended material concentration. Concentration was plotted on a logarithmic scale to align the points in an approximately straight line (implying that their distributions were approximately log-normal).

Table 7

Statistical Summary of Suspended Material

Station No.	No. Samples	Mean mg/ℓ	Coefficient of Variation	Median mg/ℓ	Quartiles mg/ℓ		Outliers mg/ℓ
			Pre-Dredging				
1	15	47.1	0.58	44	25	54	None
2	15	34.9	0.33	33	28	41	None
3	14	34.4	0.24	39	30	45	None
4	15	38.9	0.26	38	29	46	None
			Dredging				
1	48	14.5	0.26	14	12	16	25
2	51	14.7	0.27	14	12	16	26
3	28	15.6	0.34	14.5	11.5	18	None
4	51	25.4	0.79	19	14	27	55, 56, 58 58, 86, 108

81. Figures 32 and 33 show the distributions of pre-dredging and dredging samples from Stations 1 to 4. Samples from all depths and times were included. All pre-dredging and dredging samples fell along lines with similar slopes, except for samples from Station 4 taken during dredging operations. The pre-dredging samples have higher mean values, presumably caused by higher wind speed during pre-dredging. Figure 34 shows pre-dredging and dredging samples from Station 4. Both sample sets fell along approximately straight lines, but the slope for samples obtained during dredging was greater.

82. The statistical distribution of suspended material values depends on a number of factors. Dispersion near a sediment source is expected to produce additional suspended material variability and steeper slopes in concentration probability distributions. Transport characteristics involving erosion, settling, deposition, and the distribution of transport energy would also alter the statistical distributions. Most factors would be the same for all sampling sites. However,

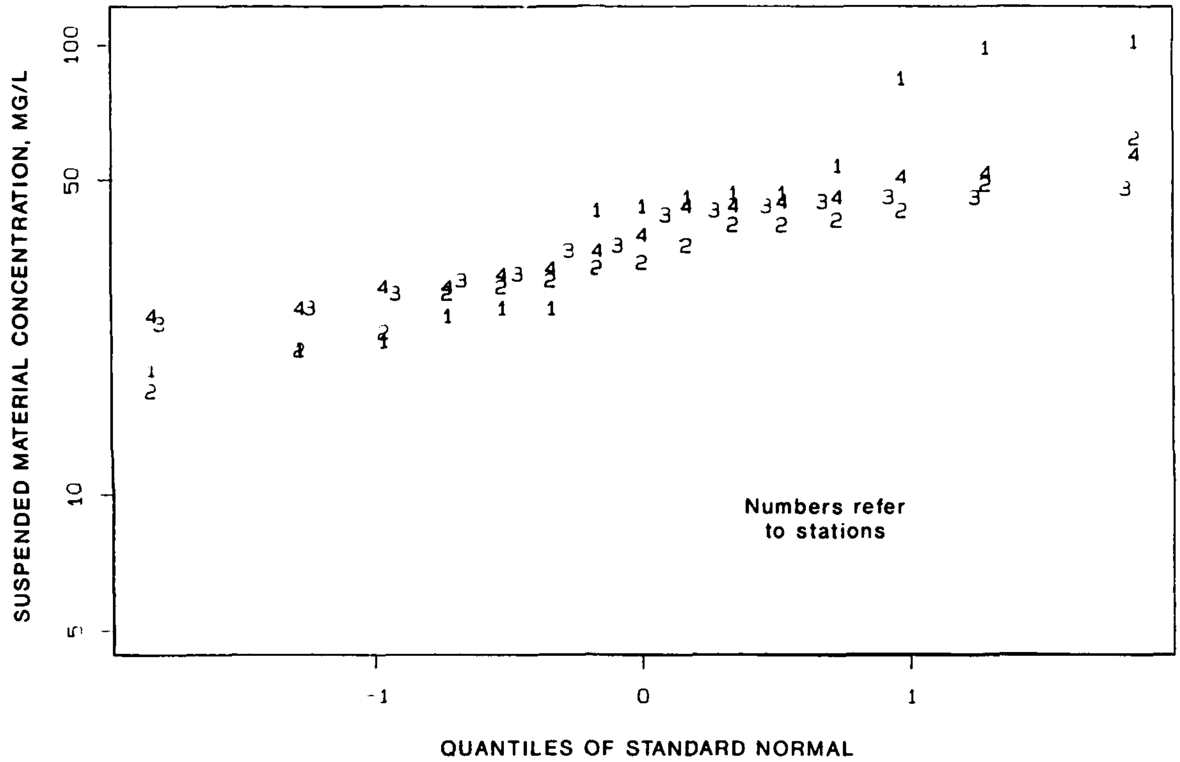

Figure 32. Pre-dredging suspended material distributions from all Team-2 stations

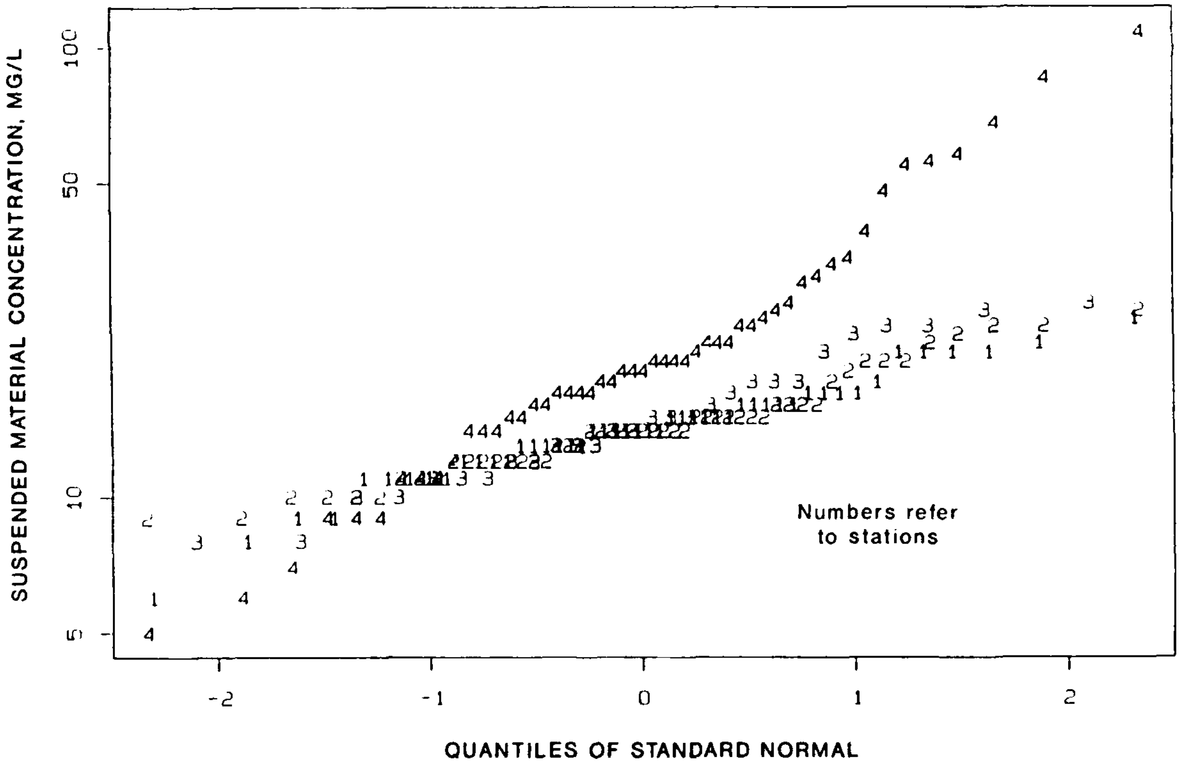

Figure 33. Suspended material distribution from all Team-2 stations during dredging operations

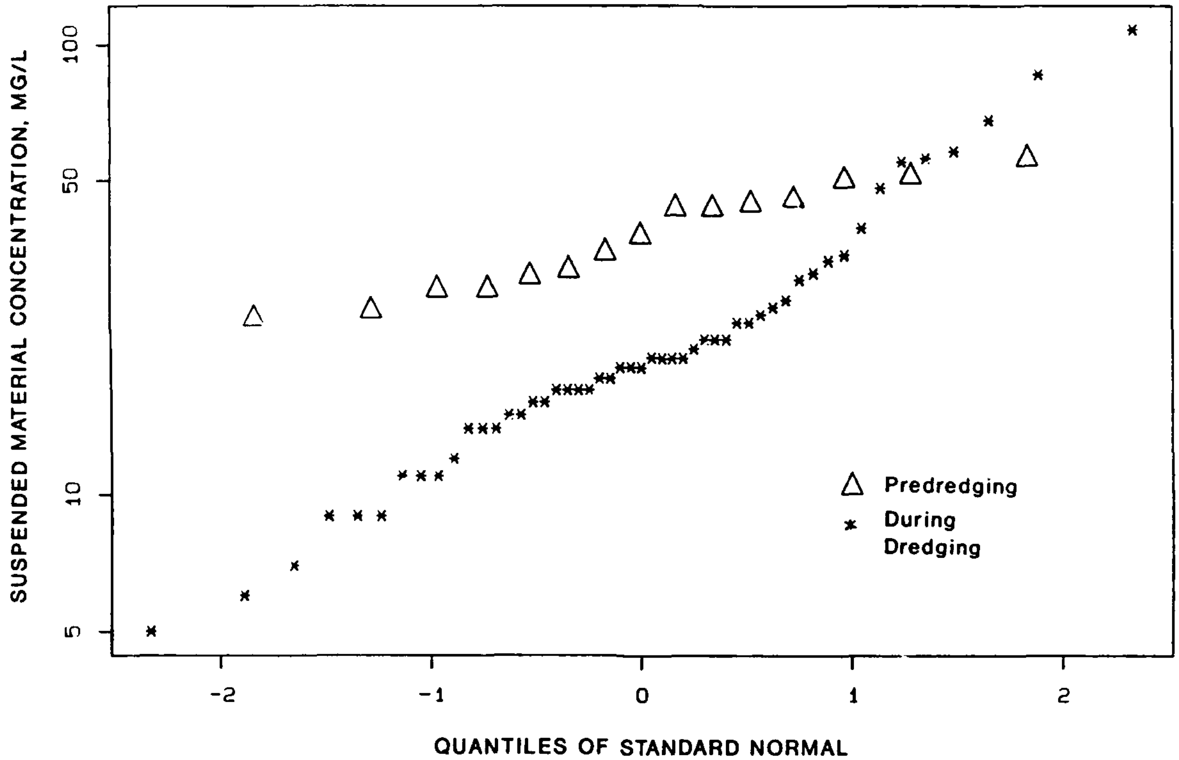

Figure 34. Pre-dredging and dredging water sample distributions

because vertical sediment distribution depends on particle settling speed, a change in sediment texture or size resulting in increased settling speed would increase the slopes of the statistical distributions. Suspended material levels were higher at Station 4, due to dredged material placement. Thus, some increase in concentration over background levels was observed upstream from the discharge point, in the direction of near-bottom current.

83. Paired scatter plots of suspended material concentration, current speed, current direction, and sampling depth for samples taken at Station 4 are shown in Figure 35. Greater suspended material concentrations generally occurred at the deepest sampling point on flood tidal phase (although the highest single value occurred on ebb tidal phase). Higher suspended material concentration and flux values occurred at moderate current speed.

Automatic water sampler concentrations

84. The automatic water sampler located on Point of Shoals (Station 2.5) and east of the discharge point took composite samples (four 200-mℓ samples per 6-hr time period) during the period of 30 September to 2 October. These concentrations are listed in Table B5. Suspended

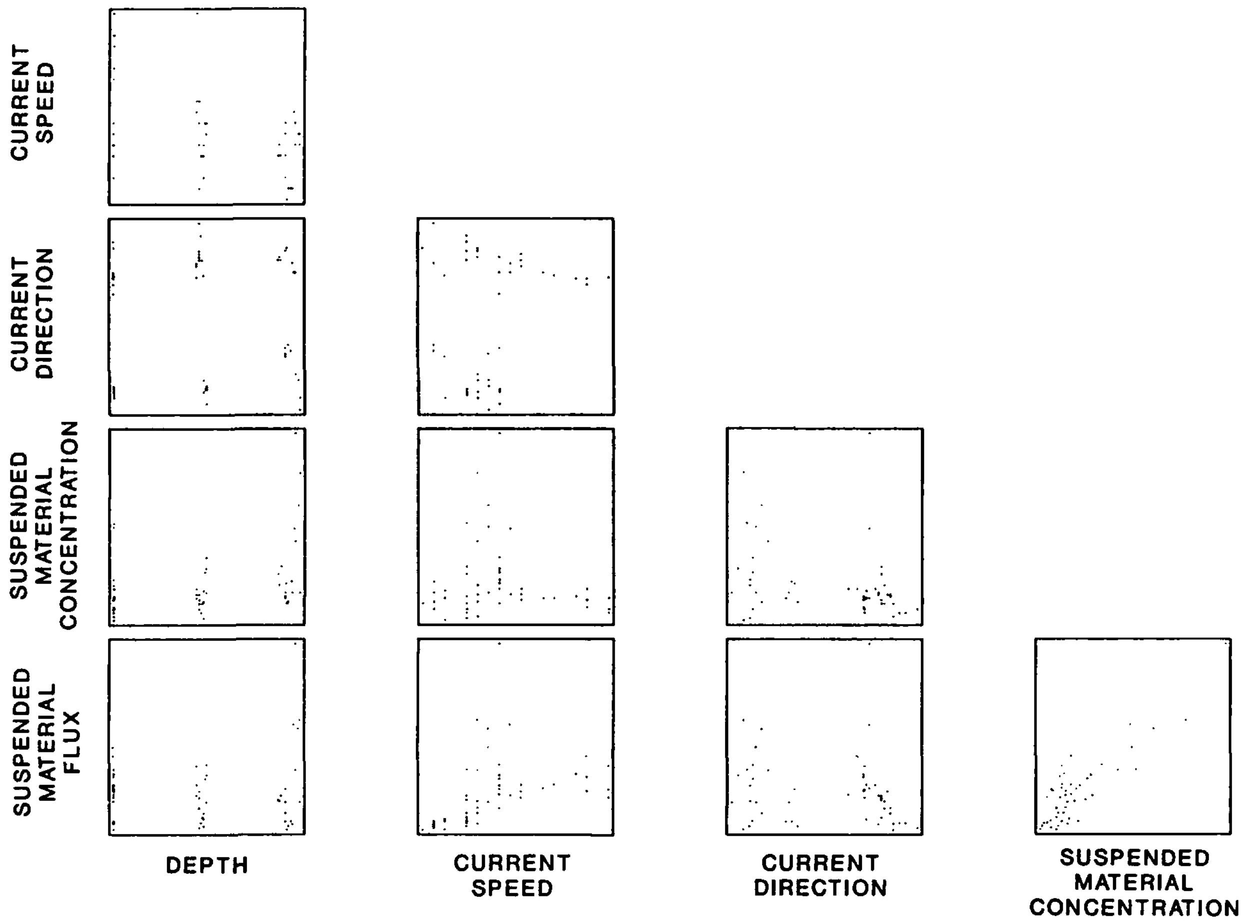

Figure 35. Paired scatter plots of suspended material concentration, current speed and direction, and depth at Station 4

material concentration from the composite samples ranged from 12 to 29 mg/ℓ, with maximum concentration found on 30 September during background monitoring. The composite samples, which represent average suspended sediment samples taken over a 6-hr period, showed an increase in concentration during flood tide. Samples taken during periods of predominantly flood tide ranged from 18 to 29 mg/ℓ, whereas ebb tide samples ranged from 12 to 16 mg/ℓ.

85. The sampler located north of the discharge point (Station 4.5) took discrete samples at 30-min intervals on 2 October and yielded suspended material concentrations ranging from 34 mg/ℓ to a maximum of 160 mg/ℓ. These concentrations are relatively high compared with

other discrete samples taken at the project site and seemed to be increasing with the increase of flood tide. The close proximity of this station to the discharge point could be responsible for the increased concentration; however, this hypothesis cannot be verified without a baseline measure of background conditions for comparison.

Transmissometer measurements

86. A transmissometer measures optical attenuation. Voltages obtained from the optical measurement are converted into suspended material concentration through calibration. Transmissivity was measured on 1 and 2 October at 1-ft depth intervals at Stations 1, 2, 3, and 4 shown in Figure 22. Because dredging occurred on both of these days, a comparison with background conditions is not possible.

87. Both a laboratory and a field calibration were conducted for determining the appropriate equation for converting light intensity to suspended material concentration. For the field calibration, water samples were taken while simultaneously measuring transmissivity. The resulting field calibration equation is

$$C = 5.737\left[10\ \ln\left(\frac{1}{T}\right)\right] - 4.857 \tag{1}$$

where T is the return voltage recorded by the transmissometer, and $10\ln(1/T)$ is the attenuation coefficient. The correlation coefficient (R^2) between the attenuation coefficient and the suspended material concentration was 0.935 for 37 data points.

88. The laboratory calibration consisted of adding a measured volume of dredged material sample taken from a leak in the discharge pipeline to site water in a test chamber kept homogeneous with a small recirculation pump. Twenty-seven concentration values were tested and the resulting calibration equation is

$$C = 3.050\left[10\ \ln\left(\frac{1}{T}\right)\right] + 2.314 \tag{2}$$

The correlation coefficient for the laboratory calibration is 0.987. Transmissometer readings were converted to concentration using the laboratory calibration, and concentration profiles are

given in Appendix D. The laboratory calibration was used because the correlation coefficient was closer to unity than the field calibration and to be consistent with the acoustic calibration. Figure 36 shows suspended material concentration plotted against the attenuation coefficient for both data sets. Two data points were excluded from the analysis of the field curve because they appeared to be spurious, and are identified as such on this figure. A comparison of the laboratory and field calibrations will be published separately, after further analysis.

89. At all stations where transmissometer measurements were taken, the suspended material concentration increased with the increased current speed associated with ebb and flood tide. Stations 1, 2, and 3 shown on Figure 22 were located in water depths of approximately 10 ft. These stations showed similar concentrations of suspended material, ranging from 5.5 to 21.1 mg/ℓ. The suspended material concentration at these three stations increased with depth if the current was ebbing or flooding; however, in slack water the concentration profiles were

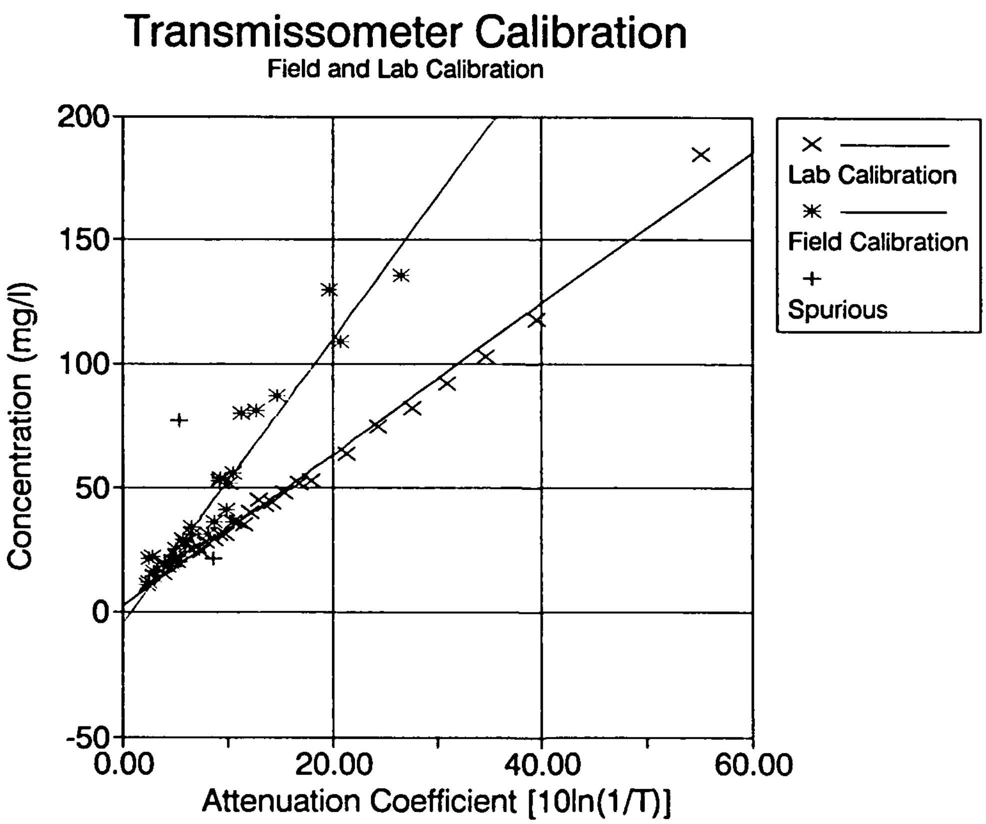

Figure 36. Transmissometer field and laboratory calibration curve

uniform throughout the water column. For example, at Station 3 on 1 October, the concentration during slack water ranged from 6.39 mg/ℓ at the surface to 5.53 mg/ℓ at the bed. During peak ebb tide at this same location, the concentration ranged from 10.7 to 13.0 mg/ℓ. Flood tide tended to suspend more material than ebb tide, even though ebb flows tended to be approximately 0.5 ft/sec faster than flood flows (1.2 to 1.4 ft/sec during peak flood as compared to 1.6 to 2.0 ft/sec during peak ebb). At Station 3 during peak flood tide, the suspended material concentration ranged from 12.9 mg/ℓ at the surface to 15.9 mg/ℓ middepth in the water column. Few data are available during peak flood tide; however, both of the profiles taken at this phase of the tidal cycle show an increase in concentration at middepth in the water column. Station 4 (Figure 22), which had a depth of about 25 ft, showed suspended material concentration greater than the other three stations. At this station, the concentration ranged from 6.74 to 130 mg/ℓ.

Acoustical measurements

90. Both the 2.4-MHz and 600-kHz acoustic systems provided acoustic backscatter intensity as a function of depth. Each signal (or ping) from the acoustic systems produces an individual vertical backscatter profile; sequential pings give a cross section of the area traversed by the survey vessel. The sediment concentration determined from backscatter intensity depends on frequency of the transmitted signal, particle size distribution, suspended material type, and total concentration.

91. Several advantages were gained by using the two different systems. First, the use of two systems allowed for confirmation of backscatter features in the water column and simplified identification of instrument-related artifacts. Because the two frequencies are preferentially sensitive to different particle sizes, comparison of the acoustical measurements has the potential to provide additional information on suspended materials if more detailed information is warranted. Such a comparison has not been done for the TBMP data. Finally, the two systems utilize different schemes for backscatter amplitude processing, and comparison can identify limitations and artifacts that result from these processing schemes.

92. Background acoustic surveys of longitudinal (north to south) transects encompassed the length of the relict channel. During dredging operations, Team 1 conducted shorter acoustic surveys across the channel (east to west) to trace the dredged material movement. Current and acoustic backscatter intensity measurements were taken during all tidal phases.

93. During the surveys, the track of the *Lynnhaven* was recorded by the vessel's navigation system and later combined with acoustic and current measurements to provide greater accuracy in profile positions and to verify BBADCP bottom tracking data. Survey tracks of the *Lynnhaven* during monitoring operations for individual surveys are given in Appendix E. Table E1 gives the starting and ending times for individual legs of each survey.

94. Backscatter intensity from the 2.4-MHz acoustic system was converted to suspended material concentration using the laboratory calibration equation, given as Equation 16. Color contour plots of suspended material concentration along each leg were then generated for all acoustic surveys. Figures referenced in this section are selected profiles from survey legs that show suspended sediment concentration as a function of depth and position along the transect. Information in the range bin (10 cm vertical depth) closest to the channel bottom, represented by concentration values greater than 130 mg/ℓ, should be ignored because of reflections off the bottom. Small gaps in the acoustical data seen in some of the profiles principally arise from gaps in navigation data and malfunctions in data acquisition equipment. Because of an error in the data acquisition software, data from the 600-kHz system were not recorded beyond a depth of approximately 17 ft. Therefore, only data from the 2.4-MHz system are shown in this report. Descriptions of individual surveys are given in Appendix F.

95. Acoustical calibration. A standard procedure in acoustical theory (Urick 1983) is to define

$$S_v = 10 \log_{10}\left(\frac{I_r}{I_i}\right) \tag{3}$$

where

S_v = volume scattering strength (dB referenced to 1 m^3)

I_r = intensity of reflected signal (W/m^2)

I_i = intensity of incident signal (W/m^2)

Both the incident and the reflected intensity are referenced to a point located 1 m from the ensonified volume and along the axis of the acoustic beam. Signal-to-noise ratio is not considered in the idealized derivation which follows.

96. The volume scattering strength can be included as part of a simplified form of the sonar equation (Urick 1983)

$$EL = SL - 2TL + S_v + 10 \log_{10}(V_e) \tag{4}$$

where

EL = echo level (dB) measured at the transducer

SL = transducer source level (dB)

TL = one-way transmission loss (dB)

V_e = ensonified volume (m^3)

In general, the ensonified volume is a function of the pulse length, transducer beam width, and distance from the source to the ensonified volume. Transmission loss, which is a function of range, can be written as

$$TL = 10 \log_{10}(r_e) + \alpha r_e \tag{5}$$

where

r_e = range (m)

α = attenuation coefficient (dB/m)

In Equation 5, the first term represents loss due to spherical spreading and the second term represents loss due to attenuation.

97. For operational purposes, the relative backscatter level BL may be defined as the sum of the echo level and twice the transmission loss, so that Equation 4 may be rewritten as

$$BL \equiv EL + 20 \log_{10}(r_e) + 2\alpha r_e = SL + 10 \log_{10}(V_e) + S_v \tag{6}$$

This form is convenient for calibration purposes, because the echo level EL can be determined from the received voltage at the transducer, and the range r_e can be determined from time gating of the signal and speed of sound in water. If an absolute calibration is not required, then it is also convenient to define a parameter K_1 such that

$$K_1 = SL + 10 \log_{10}(V_e) \tag{7}$$

From Equations 6 and 7

$$BL = K_1 + S_v \tag{8}$$

Equation 8 shows that the relative backscatter level BL is proportional to the volume scattering strength S_v.

98. Assume that the ensonified volume contains suspended particles of uniform mass m (kilograms) and uniform target strength Ts (decibels). Analogous to Equation 3, the target strength of each particle may be defined as

$$Ts \equiv 10 \log_{10}\left(\frac{Is_r}{Is_i}\right) \tag{9}$$

where the incident and reflected intensities Is_i and Is_r are now considered to apply to a single particle. The intensity ratio would be

$$\frac{Is_r}{Is_i} = 10^{0.1Ts} \tag{10}$$

Assume that the particles are well separated, i.e., there is no multiple scattering. If there are N particles per unit volume, the overall intensity ratio would be

$$\frac{I_r}{I_i} = N\left(\frac{Is_r}{Is_i}\right) = N\ 10^{0.1Ts} \tag{11}$$

From Equations 3 and 8

$$BL = K_1 + 10 \log_{10}(N\ 10^{0.1Ts}) = K_1 + Ts + 10 \log_{10}(N) \tag{12}$$

99. The number of particles per unit volume is just $N = CV_c/m$ where C is the mass concentration per unit volume (kg/m^3). Therefore, Equation 12 is equivalent to

$$BL = K_2 + 10 \log_{10}(C) \tag{13}$$

where

$$K_2 \equiv K_1 + Ts + 10 \log_{10}\left(\frac{V_e}{m}\right) \tag{14}$$

In linear units, this may be expressed as

$$C = 10^{(-0.1K_2 + 0.1BL)} \tag{15}$$

Thus, the concentration is a function of relative backscatter level.

100. The coefficients in Equation 15 were determined empirically from the laboratory calibration, which gives

$$C = 10^{(0.97 + 0.077BL)} \tag{16}$$

as well as from the field calibration resulting in

$$C = 10^{(1.43 + 0.042BL)} \tag{17}$$

According to the theory leading to Equation 15, the coefficient multiplying *BL* should have a value of 0.1. Because the empirical coefficient of *BL* is closer to the theoretical value in the laboratory calibration (Equation 16), the laboratory calibration was used in this report to convert acoustic backscatter intensity to concentration.

101. A summary of information pertinent to the calibration of the acoustic system is given in Table 8. The first column of this table provides the backscatter strength that was detected by the system during calibration. The second column gives the measured concentration obtained by removing a sample of known volume from the calibration tank or in the field and determining the concentration of suspended material. The third column is the computed concentration obtained by inserting the value of the backscatter strength in column 1 into Equation 16 for the laboratory calibration and Equation 17 for the field calibration.

102. Figure 37 shows suspended material concentration plotted against backscatter intensity for both the laboratory and field data sets. Also shown are the best-fit lines for each data set. The field and laboratory data coincide reasonably well for backscatter intensities higher than approximately 5 dB. At lower intensities, however, there is a divergence of the two calibration curves. The concentrations resulting from the field samples are higher at lower intensities than

Table 8
2.4-MHz BBADCP Concentration Measurements

Backscatter Strength dB	Measured Concentration mg/ℓ	Computed Concentration mg/ℓ
	Laboratory Calibration	
		Equation 16
-2.8	5.7	5.7
2.9	12.3	16.2
4.2	23.0	20.5
7.7	42.3	38.7
13.6	106.0	113.3
17.6	230.6	234.6
23.5	484.3	686.3
25.4	1008.1	969.6
	Field Calibration	
		Equation 17
-6.2	18.0	14.8
-4.5	19.0	17.7
-4.0	20.0	18.6
-3.7	22.0	19.2
-3.7	20.0	19.2
-2.4	18.0	22.0
-2.1	20.0	22.7
-1.3	21.0	24.6
-0.9	36.0	25.7
1.6	31.0	33.3
2.4	36.0	36.1
3.3	28.0	39.7
3.8	31.0	41.8
6.3	54.0	54.1
6.5	53.0	55.3
7.1	29.0	58.8
7.6	34.0	61.9
7.8	52.0	63.2
8.0	77.0	64.6
8.1	41.0	65.2
8.5	81.0	68.0
8.7	56.0	69.4
11.6	87.0	93.7
11.6	136.0	93.7
11.7	130.0	94.7
11.9	80.0	96.7
13.0	109.0	108.4

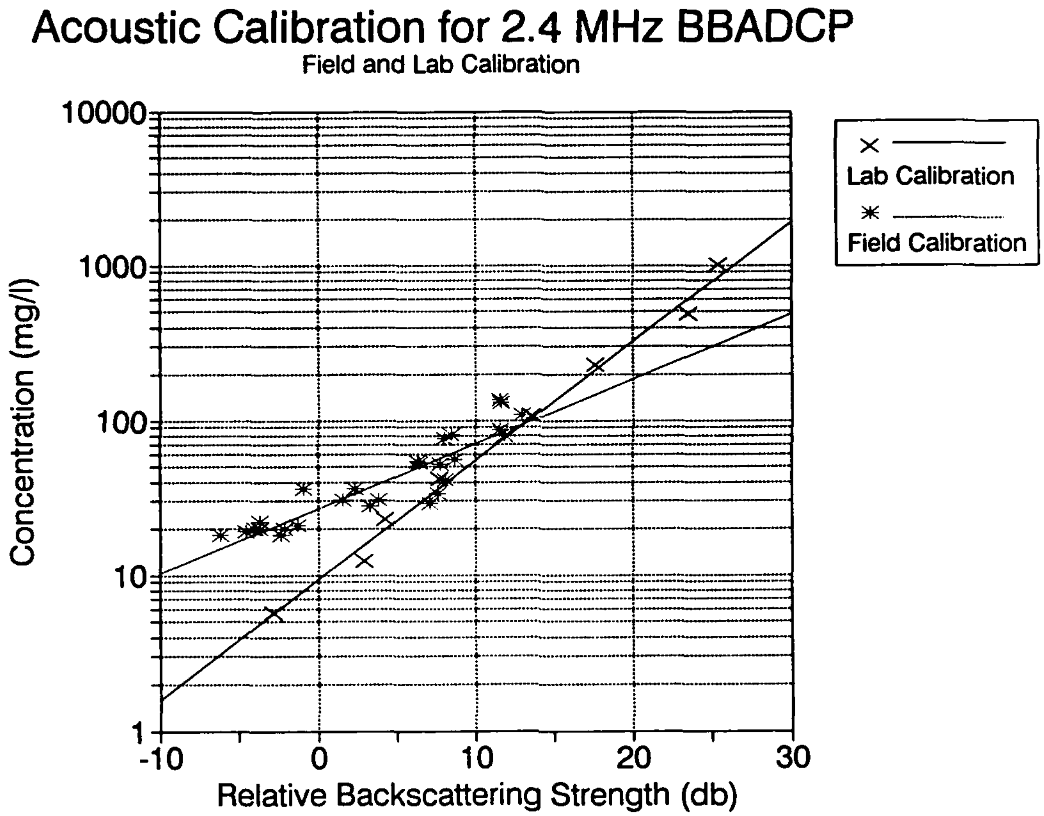

Figure 37. BBADCP field and laboratory calibration curves

the corresponding concentrations used in the laboratory calibration. Differences between laboratory and field calibration at low concentration are approximately 10 to 15 mg/ℓ. Both laboratory and field calibrations have limitations. A laboratory calibration does not account for such factors as salinity variation, current shear, and unpredictable backscatterers such as turbulence vortices. In contrast, a point sample taken in the field represents an instantaneous concentration of a small sampling volume of a time-dependent system with many length and time scales of motion. Constant concentrations as obtained in the laboratory calibration provide a more reliable relation between backscatter intensity and concentration in this sense. In the present situation, close agreement between the two procedures improves confidence in the acoustical remote sensing field measurements. Further consideration will be given to the appropriate calibration technique and will be documented separately.

103. Application of acoustic backscatter for measuring suspended sediment concentration is a topic of ongoing research and development within the PLUMES project. Although the

concentration map presented in this report is used as a description of the main spatial and temporal features of suspended sediments at the project site, the results must be interpreted with caution.

104. Background. Acoustical measurements performed on 30 September show a wide range of suspended material concentrations during the tidal cycle. Observations during ebb tide showed low concentration (10 to 20 mg/ℓ) throughout the water column and in the deeper areas of the channel. A moderate increase in suspended material concentration up to 30 mg/ℓ was observed toward the southern portion of the channel, with the highest concentrations located close to the river bottom (Figure 38). When currents were slow and the tide was slack, concentrations less than 20 mg/ℓ were observed throughout the channel at all depths. During flood tide, suspended material concentration increased significantly as bottom sediment was resuspended by the current. Patches of suspended material with concentrations as great as 70 mg/ℓ were observed near the surface, both in the channel and on Point of Shoals during the background surveys. Significantly higher concentrations, exceeding 100 mg/ℓ, were also observed near the bottom of the channel in the deeper sections. These conditions can be seen clearly in Figure 39, which shows a profile of concentrations taken along the channel during peak flood tide, when the current speed was approximately 1.0 ft/sec and directed to the northeast. The data indicate that the channel acts as a trap for suspended material that is deposited on the bottom during low current speed and is then resuspended during periods of peak currents. The observation also indicates that, during peak flood currents, resuspended material from the channel is advected toward the shore and away from Point of Shoals.

105. During dredging. Nine acoustical surveys (numbers 4-12) were conducted from 1 to 3 October during dredging and placement operations. Surveys 4, 5, and 8 were conducted during ebb tide; Surveys 7, 10, and 11 were conducted during flood tide; and Surveys 6, 9, and 12 were conducted during slack water or weak current. For each survey, a number of transects were run across the channel extending north and/or south of the discharge point. The number of transects in a survey depended on the extent of the discharge plume as detected by the acoustic instruments.

106. Data collected during these surveys show that the dynamics of the discharge plume are primarily determined by the tide. Surveys run on different days at approximately the same tidal phase show essentially identical distributions of naturally suspended material within the

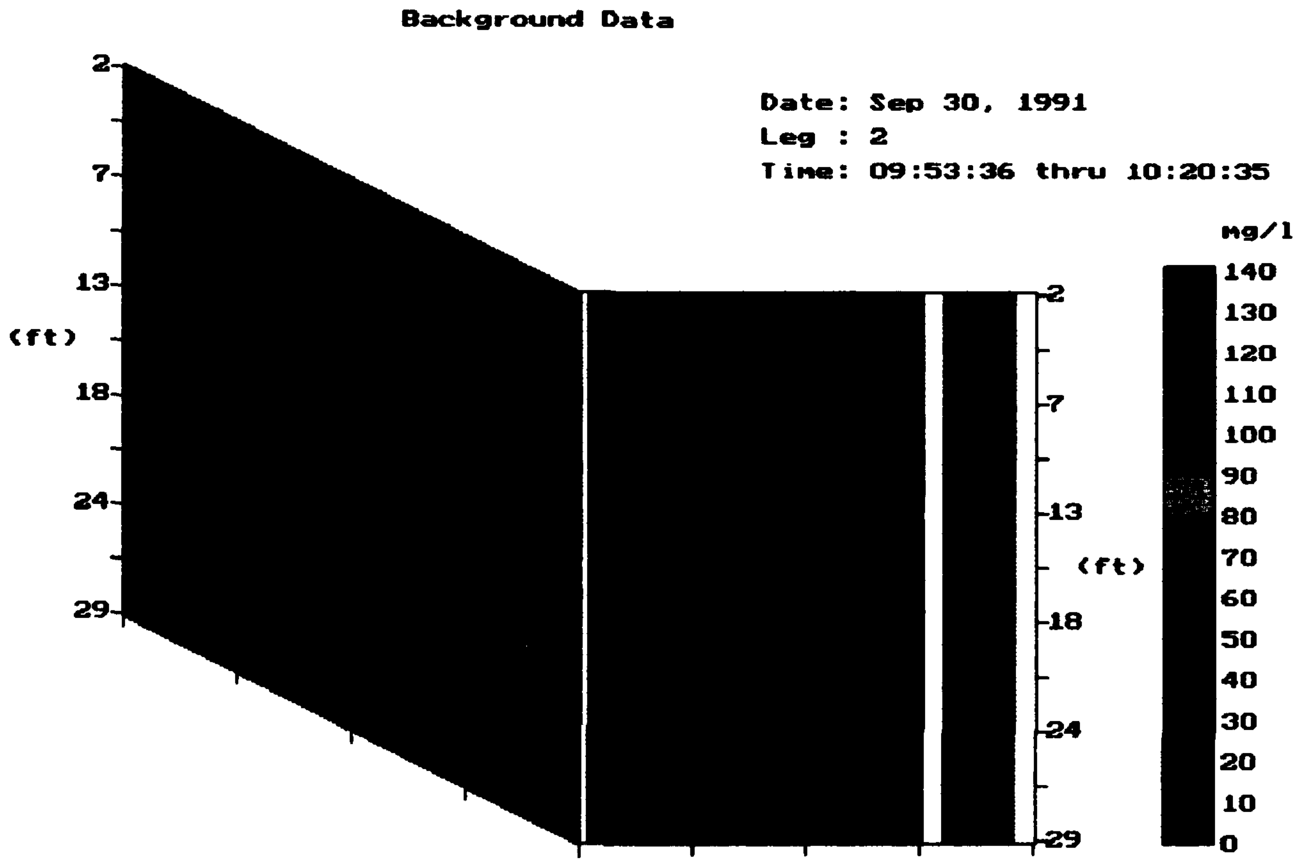

Figure 38. Background acoustic profile along channel during ebb tide (one horizontal gradation equals 1,000 ft)

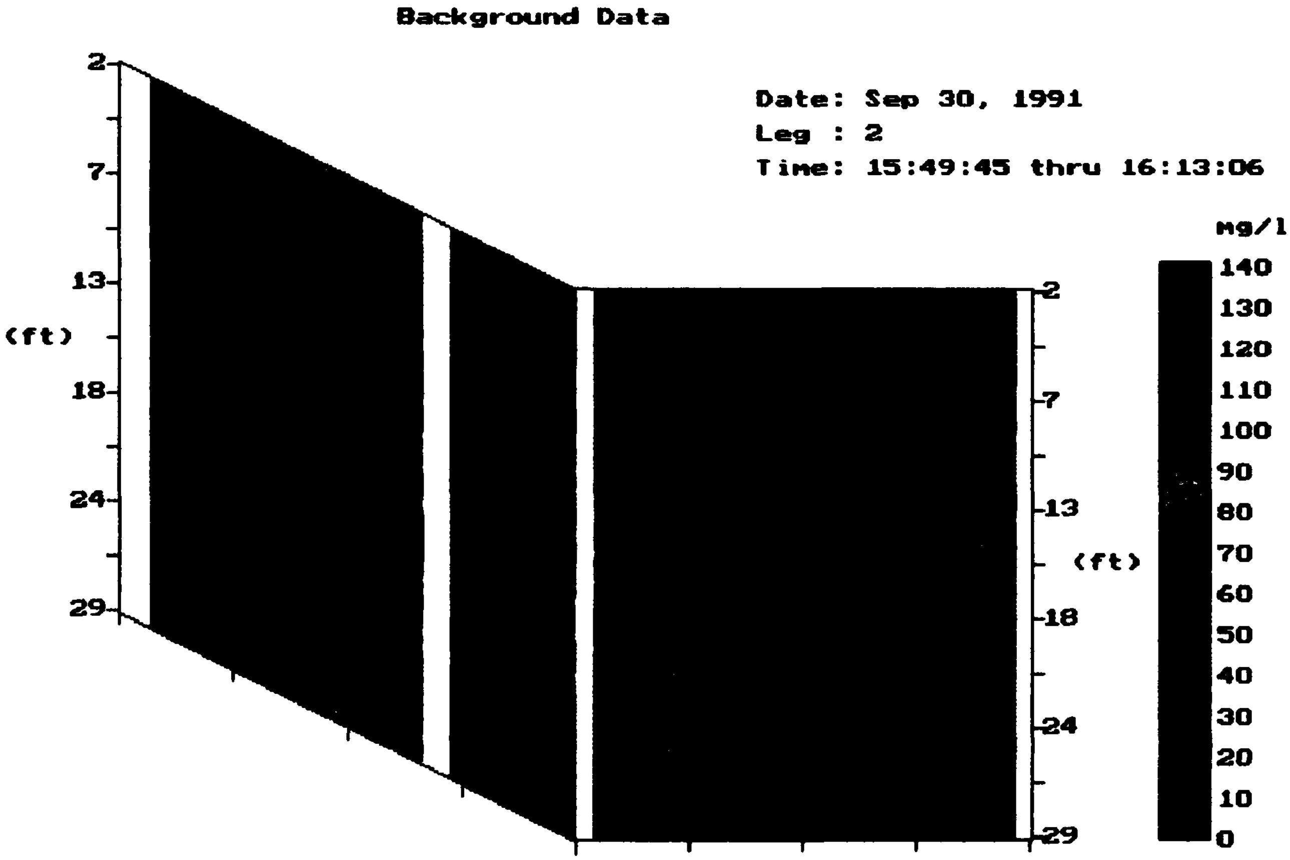

Figure 39. Background acoustical data during peak flood tide
(one horizontal gradation equals 1,000 ft)

survey area; the discharge plume behaves like the natural suspension accumulating on the bottom of the channel. Results of the acoustic surveys are summarized for each of the tidal phases in the following paragraphs.

107. During periods of strong ebb current, survey transects closest to the placement site showed that most of the dredged material descended directly into the relict channel (Figure 40). A layer of unsettled dredged material was observed to spread for several hundred feet along the bottom of the channel southward of the discharge point. Movement of this layer halted at the slope of Point of Shoals (Figure 41), and material never extended upward and over onto Point of Shoals in any observations. Transects located close to the discharge point also showed a narrow plume of dredged material extending from the surface to the bottom in the center of the channel. This plume moved with the current south and along the channel, dispersing toward the bottom and finally disappearing a few hundred feet from the discharge point. A thin layer of dredged material was observed on the bottom of the channel, just north of the discharge point. Other than the well-defined plume and some clouds of dredged material located directly above the bottom, little suspended material (approximately 10 to 20 mg/ℓ, at most) was detected in the channel. Monitoring along all survey transects during ebb tide indicated concentrations less than 20 mg/ℓ in the upper water column on the Point of Shoals side of the channel. Clouds of suspended material, with concentration ranging from 50 to 70 mg/ℓ, were observed on the shore side of the channel during most survey transects. These clouds were well separated from the discharge plume by clear water in the channel and appeared to be formed from a natural resuspension of sediments by the current in the shallow water west of the channel.

108. During slack water, the dredged material settled directly into the placement site (Figures 42 and 43). Figure 43 is a vertical profile taken on 3 October during slack water when no dredging was occurring. This figure shows little suspended material in the water column at the placement site, indicating that the majority of the dredged material had settled to the site bottom. During dredging, a thin layer of unsettled material was seen on the bottom of the channel north and south of the discharge point. A narrow vertical plume of dredged material was observed only in survey transects closest to the discharge point. Concentrations less than 20 mg/ℓ were observed in the water column throughout the channel, except in the vicinity of the discharge point and near the material accumulated on the bottom. The surveys provided no evidence that dredged material reached Point of Shoals during slack water.

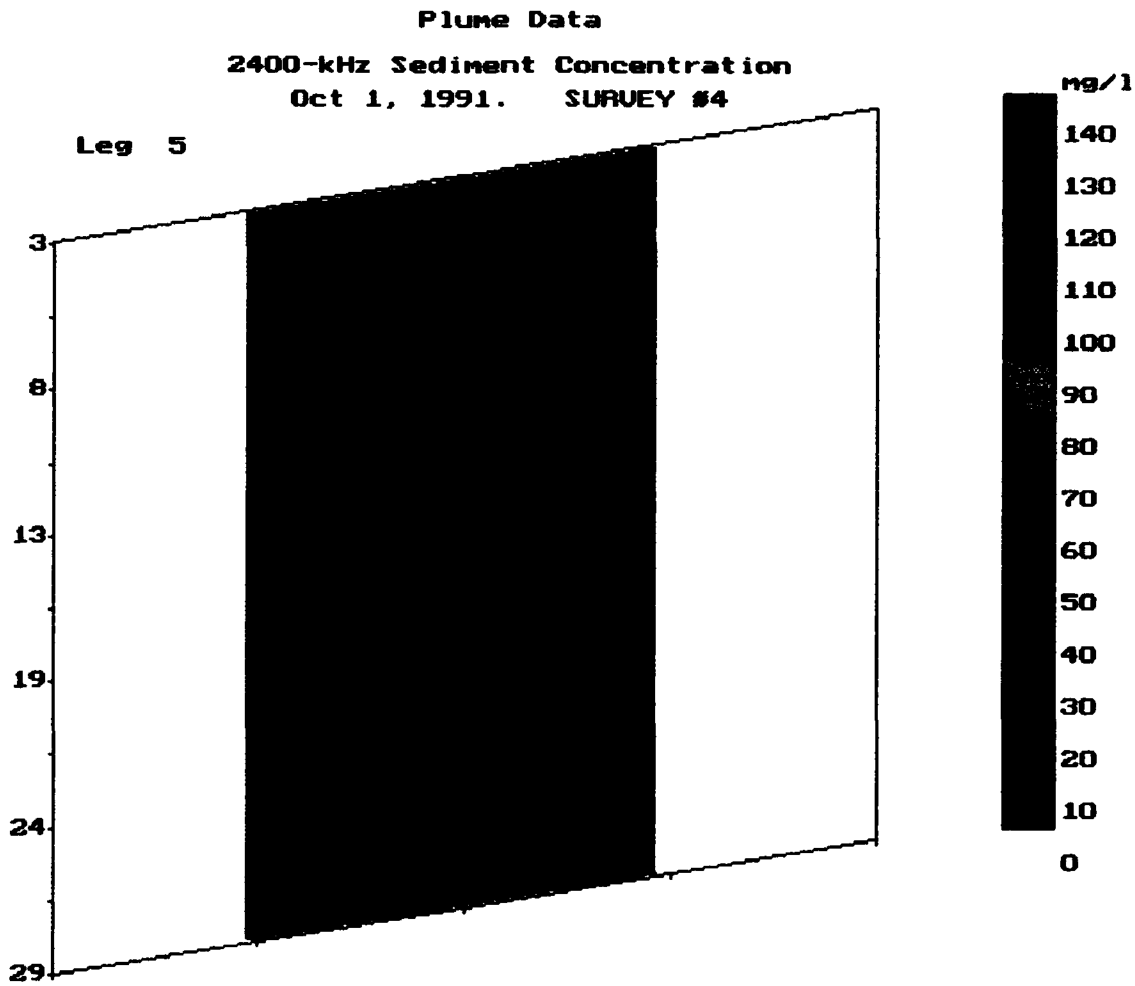

Figure 40. Cross-channel survey leg showing dredged material discharge at discharge point during peak ebb tide (one horizontal gradation equals 300 ft)

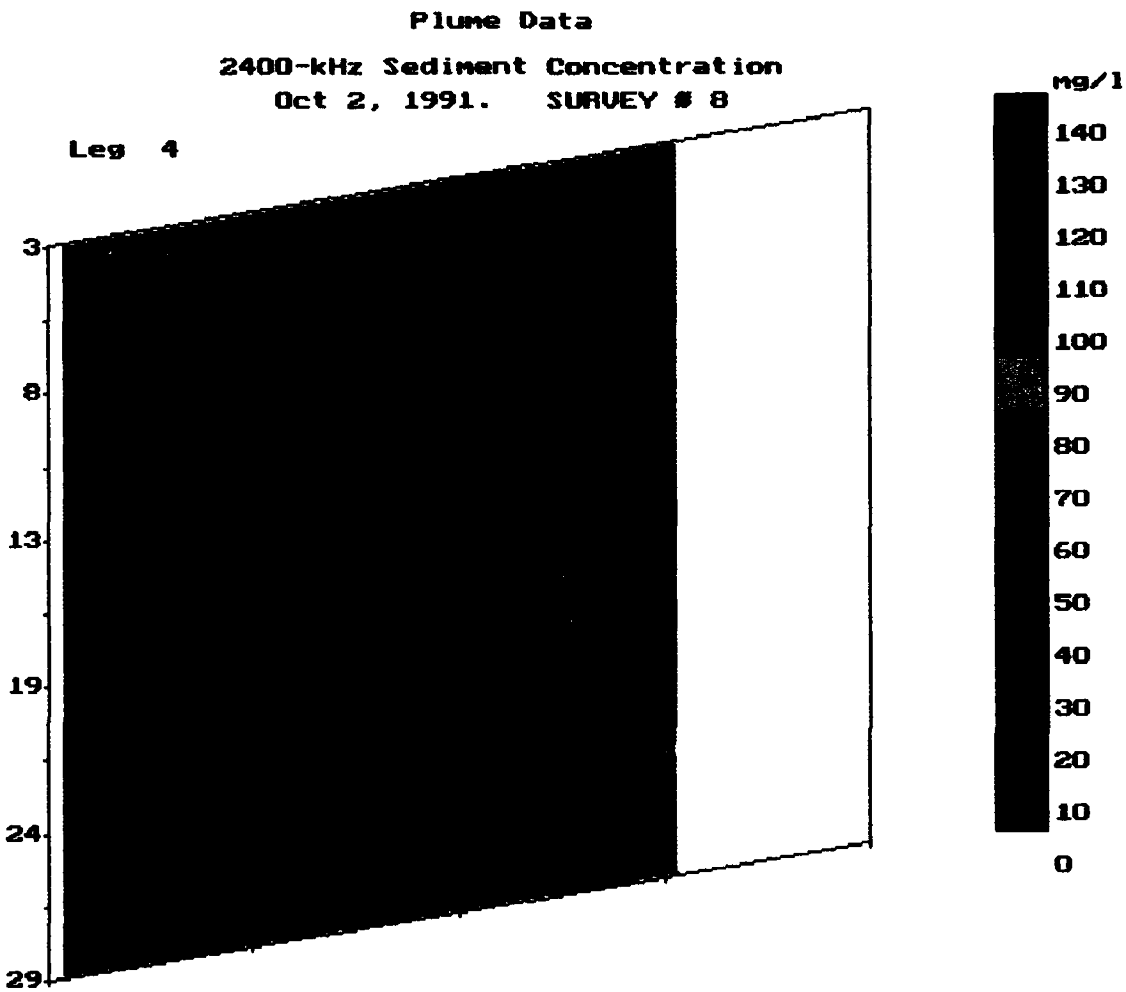

Figure 41. Cross-channel survey leg of acoustic data during plume monitoring, south of discharge point during ebb tide (one horizontal gradation equals 300 ft)

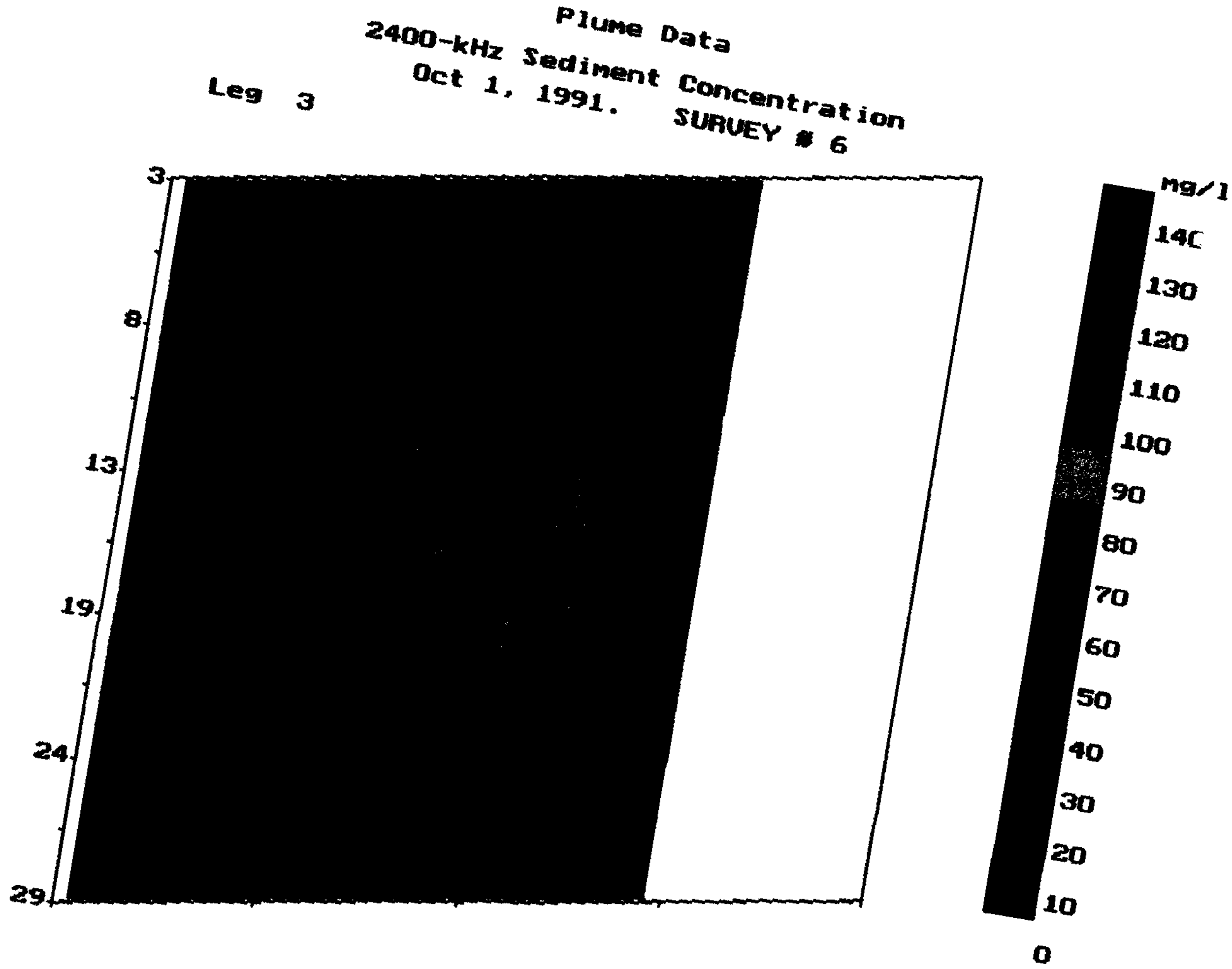

Figure 42. Dredged material discharge at discharge point during slack water (one horizontal gradation equals 300 ft)

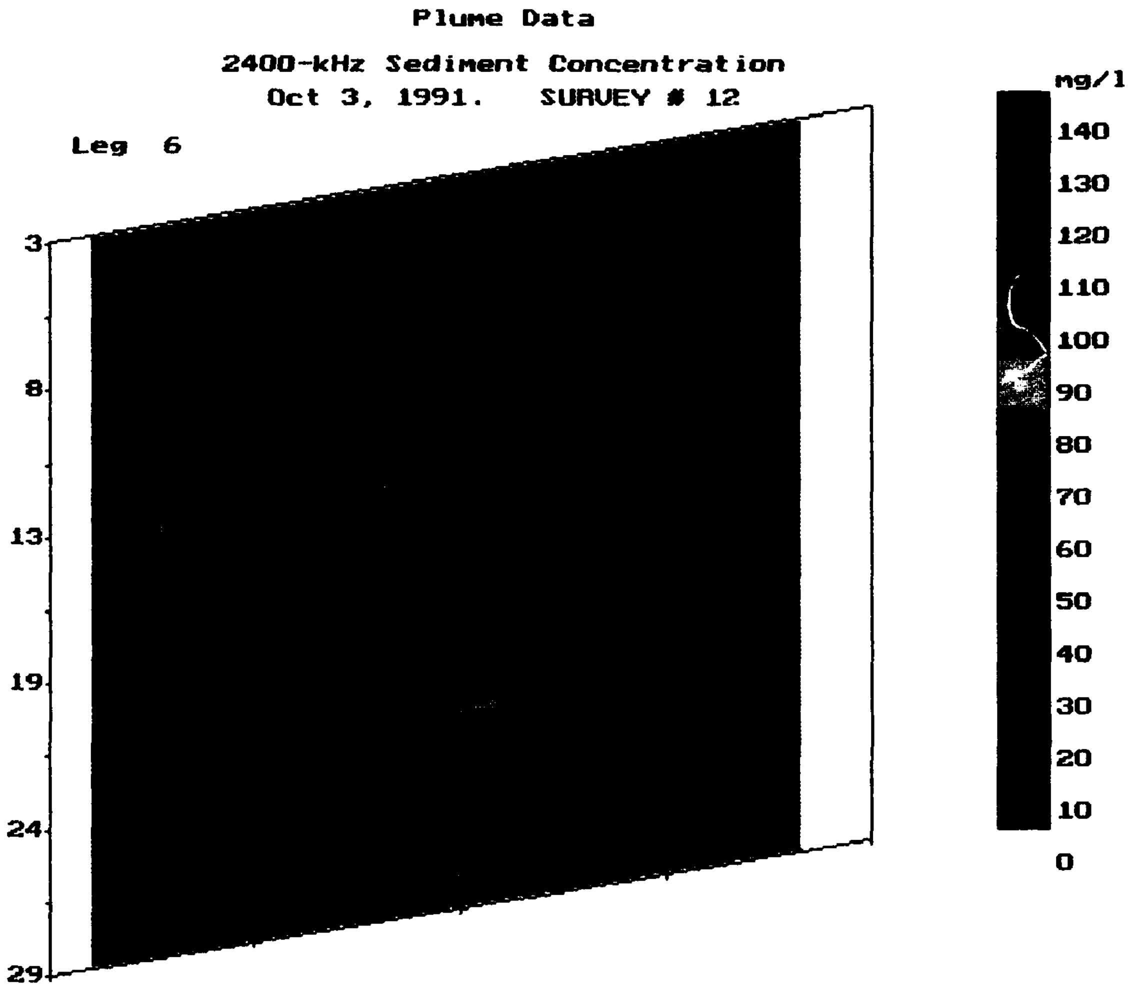

Figure 43. Cross-channel survey leg taken at slack water during a period of no dredging (one horizontal gradation equals 300 ft)

109. During periods of peak flood current, a significant increase in the amount of suspended material was observed throughout the entire water column (Figure 44), similar in magnitude to background survey observations made during peak flood. A bottom layer of unsettled dredged material was observed at the discharge point and to the north, aligned in the direction of current flow. Survey transects north of the discharge point showed this layer spreading and moving out of the channel and in the direction of shore. Clouds of suspended material, with maximum concentrations of 100 mg/ℓ, were observed immediately above this layer and were advected by the flood current in the direction of shore. The vertical plume of dredged material detected at the discharge point during ebb current and slack water was quickly dispersed and advected to the northwest by the strong flood current. Suspended material concentrations in the upper part of the water column on the shore side of the channel were typically low, ranging from 10 to 40 mg/ℓ. On Point of Shoals, suspended material concentration through the water column ranged from 20 to 40 mg/ℓ. During one survey leg, the concentration reached as much as 60 mg/ℓ. However, because of the current direction and the fact that concentrations were less than background measurements at the same location during similar tidal stage, the origin of the clouds of material over the shoals appeared to be natural sediment resuspension. No evidence of dredged material reaching the shoals during flood tide was found in the acoustic surveys.

<u>Comparison of suspended material observations</u>

110. During ebb tide and slack water, the dredged material was found to move downstream of the discharge point, the majority of which was confined below the 10-ft topographic contour. At Station 32 (Figure 14), located just downstream of the discharge point, the suspended material concentration at the channel bed was several thousand mg/ℓ. This large concentration of material did not reach Station 1 (Figure 22), which was located approximately 200 ft south of the discharge point in water shallower than 10 ft.

111. During flood tide, large amounts of suspended material (160 mg/ℓ) were observed at Station 4.5, where an automatic water sampler was located. This implies that material advected 250 ft upstream in the channel by the flood tide. At Station 4 (Figure 22) greater bottom concentrations (maximum 108 mg/ℓ) were noted during flood tide at times of high wind. Material in these Station 4 samples was moving upstream along the channel bed at depths of approximately 15 ft. Team 1 took water samples at Stations 17, 19, and 22 during flood tide. None of these samples possessed concentrations of more than 20 mg/ℓ. At Station 21, near Point

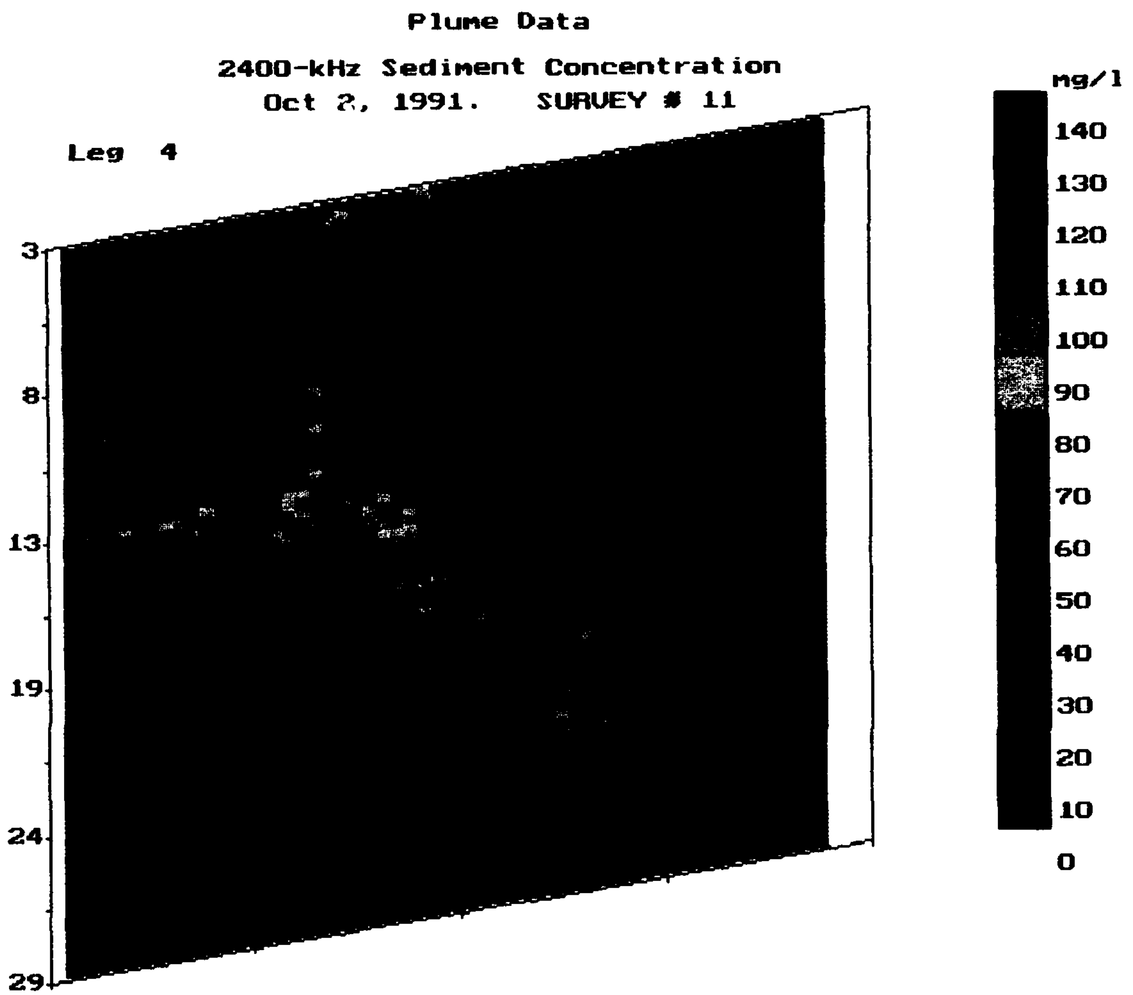

Figure 44. Cross-channel survey leg near discharge point during peak flood tide (one horizontal gradation equals 300 ft)

of Shoals, higher concentrations were noted at a depth greater than 20 ft. No samples from Station 2, 2.5, or 3 (Figure 22), located on Point of Shoals, showed levels of suspended material during dredging that were higher than background conditions. The acoustical data typically showed 20- to 40-mg/ℓ concentrations at Point of Shoals during flood tide. The acoustical data are consistent with the in situ measurements because, even though the acoustical measurements indicate higher concentrations, it can be seen in Figure 44 that in obtaining a point sample in the area of Point of Shoals, the probability would be greatest to obtain a sample of 20-30 mg/ℓ.

112. The five independent observations (two water sampling teams, automatic water samples, transmissometer readings, and acoustical instrumentation) of suspended material concentration showed remarkable consistency. In addition, the measurement results agree with the findings of DeLoach, Getchell, and Waring (1982), whose field observations showed that the discharge plume remained relatively near the outfall pipe and below the 15-ft contour.

PART IV: CONCLUSIONS[1]

113. Background conditions and dredged material plumes were monitored for 5 days off Tylers Beach, Virginia, and the data were subsequently analyzed as a cooperative effort between the Norfolk District and research work units of the DRP. The project-specific objective was to determine if dredged material would reach Point of Shoals, a shallow rock outcrop located adjacent to the discharge site. Point of Shoals is an important environmental resource in the Chesapeake Estuary. The DRP research objective was to conduct a rigorous field test of a remote sensing, acoustic-based, material concentration and flow measurement system. In order to meet these objectives, equal emphasis was placed on in situ monitoring and on acoustic surveys.

114. In situ monitoring provided direct measurements of the total weight of suspended material in the water column, together with data on the temperature and salinity of the water. The in situ monitoring also included measurement of suspended solids by optical transmission and of current velocity by standard mechanical meters. Other project measurements were bathymetric surveys and recording of the water surface elevation. The in situ monitoring served the dual purpose of providing direct physical measurements at the site and data for *ground truthing* the acoustic system. The acoustic instrumentation served a critical function of detecting and tracking the dredged material discharge plume to guide the in situ monitoring, because the plume could not be located visually on the surface owing to the natural turbidity of this river estuarine environment. The acoustic surveys efficiently and effectively delineated the perimeter and movement of the plumes as they responded to changes in the current and depth at the study area.

Discussion

115. The present work extends the methodology of previous dredged material plume monitoring projects in performing a thorough calibration of a high-resolution acoustic sensor to provide quantitative synoptic estimates of the suspended material. Both field and laboratory calibrations were conducted for consistency and for research purposes, and the laboratory and

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[1]Written by Dr. Nicholas C. Kraus.

field calibrations produced comparable empirical curves. The suspended material and current velocity measurements obtained with the acoustic system were in general agreement with corresponding in situ measurements.

116. The research objective of the DRP PLUMES project was met in demonstrating that reliable remote sensing measurements of dredged material plumes can be performed in a shallow-water estuarine environment. In situ suspended material sampling is part of the PLUMES data collection methodology. Such sampling need only be performed for ground truthing (particle size, and the suspended material concentration) of the acoustic instrumentation and for making supplementary measurements of characteristics such as salinity and water temperature. As opposed to presently available optical methods and in situ sampling (which in practical applications are limited to making measurements of relatively small sample volumes), PLUMES acoustic instrumentation provides wide-area coverage through the water column to within 1 to 2 ft from the bottom. This is similar to the access depth with standard in situ samplers.

117. A comprehensive data set on physical environmental conditions was obtained to determine if material discharged through the pipeline would reach Point of Shoals. Monitoring was conducted for 5 consecutive days: the first 2 days prior to the onset of dredging operations to obtain measurements of the naturally occurring (background) sediment movement, and the last 3 days while dredging and dredged material placement operations were taking place. The results of these observations are summarized in the next section.

Conclusions

118. Water and sediment movement in the James River within the study area off Tylers Beach is dominated by the tide, wind, and locally generated wind waves. The current is directed to the northeast during flood tide and to the southwest during ebb, achieving speeds of 2 ft/sec during the observation period. Water salinity also showed a tidal influence, varying from about 10 ppt during slack water to about 14 ppt during flood tide.

119. No significant stratification of temperature was observed during the monitoring period. The stratification in salinity showed a maximum difference in profile of 2.4 ppt. Current speed and direction were typically uniform through the water column. Notable current shears were detected when the wind speed was 12 mph.

120. The magnitude of the naturally occurring concentration of suspended material in the study area closely follows the tidal cycle, with minimum concentrations found during slack water. During slack water, concentrations in the range of 10-30 mg/ℓ were observed throughout the water column at the study area. During normal peak ebb and flood currents, suspended material concentrations of 60-70 mg/ℓ were observed throughout the water column. In some cases, concentrations slightly greater than 100 mg/ℓ were observed near the bottom of the channel.

121. Concentrations of suspended material measured by both water sampling and acoustic surveys during times of dredged material discharge were in the range of the background measurements, except at the bottom in the immediate vicinity and down current of the discharge pipe, where concentrations reached above 15,000 mg/ℓ. These high concentrations were only observed near the bottom, with typical concentrations measured in the mid- and upper-water column. Clouds of suspended material occasionally observed on Point of Shoals containing concentrations of up to 60 mg/ℓ appeared to have originated as resuspension events on the shoals themselves, as judged by the observed direction of the current. On one day, a short period of relatively high wind speed (approximately 10 mph) occurred, and suspended material concentration increased at all sampling stations, for example, from a typical range at one station of 19 to 47 mg/ℓ to 85 to 102 mg/ℓ at the time of higher wind speed. During windy days and storms, the naturally occurring concentration is expected to be orders of magnitude higher. Except for the region of the bottom at the discharge point, suspended material concentrations measured during dredged material placement operations were similar to concentrations observed during comparable tidal phases in calm weather when no dredging took place. In fact, suspended material concentrations during dredging were found to have smaller magnitudes than concentrations expected during storms or even moderately windy days. DeLoach et al. (1982) arrived at the same conclusion after field monitoring and numerical modeling of the system.

122. Suspended material in the study area is transported primarily along the main axis of the channel, with little material crossing the channel between the shore and Point of Shoals. The topography of the channel and dominant direction of the tidal current along the channel inhibit transport of suspended material from one side of the channel to the other. During flood tide, however, some material (30 to 40 mg/ℓ for approximately 1 hr) is advected out of the channel and toward the shore by the tidal current.

123. Monitoring during dredged material discharge showed no evidence to indicate that the dredged material migrated on to Point of Shoals. During slack water, the material remained within the channel, settling on the bottom with high concentration within a few hundred feet of the discharge point. During peak ebb current, the discharged material moved southward several hundred feet along the bottom of the channel to rest against the slope of Point of Shoals at the bottom with concentrations of several thousand mg/ℓ at a depth of 26 ft, but never reaching above the 15-ft contour or the top of Point of Shoals. During peak flood current the discharged material moved a greater distance north along the bottom of the channel (material was observed near the bottom approximately 1,500 ft north of the discharge point), but did not reach the top of Point of Shoals. Therefore, under calm weather conditions such as those encountered during the project, the discharge of dredged material at the placement site did not cause an increase in the naturally occurring concentration of suspended material on Point of Shoals.

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APPENDIX A: DISPERSION ANALYSIS FOR PIPELINE DISCHARGE[1]

Introduction

1. Field monitoring of dispersion from a dredged material disposal operation near Point of Shoals, Burwell Bay in the James River Estuary was conducted by the US Army Engineer Waterways Experiment Station. The pipeline disposal took place at a stationary vertical termination located in the deepest part of an abandoned river channel and was associated with dredging of the Tylers Beach, Virginia, navigation project by the hydraulic cutterhead *Dredge Richmond*. The dredge was operated by Cottrell Engineering Corporation between 1 and 4 October 1991. Field monitoring supplied data and an excellent opportunity to test and refine preliminary predictive techniques under development as part of the ongoing Dredging Research Program (DRP). This appendix describes the procedures used to analyze initial dredged material dispersion and application to this site, in support of the field observations.

2. Before proceeding with a description of analysis procedures, basic concepts entering the dispersion analysis are defined:

a. A **plume** is a self-organized formation hydrodynamically driven by density differences between it and the ambient flow.

b. An **underflow** is a flowing fluid or suspension layer separated from the overlying water by a sharp density gradient.

c. **Entrainment**, as used in this discussion, is the active incorporation by a turbulent-mixed fluid layer of fluid from an adjacent layer. There are two fluid entrainment processes described in this appendix: ambient fluid (water) entrained by the plume and the underflow fluid (suspension) entrained by the ambient flow.

d. Average **dilution** is defined as the ratio of plume concentration to discharge concentration. Therefore, dilution is the inverse of the discharged-material volume concentration and starts at 1.0 at the outflow port.

e. **Stripping** refers to the small amount of material that is normally removed from a descending plume by the ambient flow.

f. **Dispersion** is hydraulic transport of material by convection, advection, and diffusion in a shear flow. When the material in transport does not alter density fields and disperses in the same manner as ambient material, dispersion is termed passive and **passive dispersion** is driven by the ambient turbulence and flow fields. A **cloud** is a detectable pattern of material undergoing passive dispersion.

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[1]Written by Mr. Allen M. Teeter.

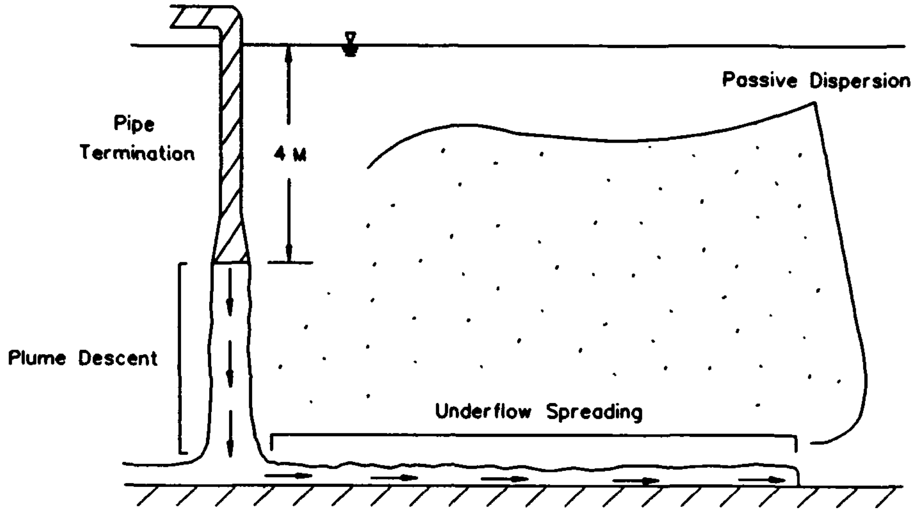

Figure A1. Three dispersion phases of discharge from a pipeline

g. The **ambient** is the background consisting of natural suspension and flow fields.

3. Dispersion processes for pipeline-disposed dredged material can be classified as near-field or far-field. Near-field physical processes begin at the discharge port and include the descent of the dense negatively buoyant plume and impingement of the dense plume on the bed. Both of these processes are direct results of the dynamic characteristics of the discharge. The far-field processes include the spreading of a dense underflow along the bottom, and of concern to project objectives, the passive dispersion caused by ambient turbulence and flow fields. Far-field dispersion is of greatest concern, but information on near-field dispersion is required for its evaluation.

4. This appendix describes procedures used to analyze three dispersion phases important to initial dispersion for pipeline disposal of dredged material. The three phases are shown in Figure A1 and are defined as follows:

a. Initial descent of a dense plume to the bed, entrainment of ambient water into the plume, and the formation of an underflow.

b. Bottom spreading of material and entrainment of the underflow into the overlying ambient flow.

c. Incorporation of dredged material stripped from the plume and entrained from the underflow into ambient suspended sediment fields.

5. The analytic framework that will be described consists of first-order calculation procedures for the dispersion of sediment material from a pipeline disposal. The procedures are used to check

the consistency of field measurements, to identify dominant physical processes, and to fill information gaps. Information gaps are to be expected and can be caused by difficult or impossible field sampling conditions. The DRP is studying dispersion from open-water sites, and the PLUme MEasurement System (PLUMES) described in the main text has been used to provide much more field information than has been previously available.

Descent of a Dense Plume to the Bed

6. Pipeline-discharged dredged material initially has negative buoyancy and, if directed vertically downward, momentum, both of which cause descent of discharged material toward the bed. This section applies to single-port, downward-directed, negatively buoyant plumes. During descent, some ambient fluid is entrained into the dense plume. Initial dilution during plume descent enters the process of sediment dispersion from the site because (a) it reduces the density difference between the underflow and the ambient, thereby increasing subsequent entrainment of the underflow by the overlying flow, and (b) it increases the underflow volume and decreases viscosity, increasing spreading along the bottom. Entrained fluid dilutes the descending plume.

7. The initial phase of plume behavior in the vicinity of the outlet port is called the zone of flow establishment and extends a distance of about six port diameters along the trajectory of the plume. Transverse plume velocity and concentration profiles in this zone develop from top-hat to Gaussian shapes. Dilution and spreading are minimal in this zone. This zone must be treated separately in numerical and analytic plume analyses.

8. Unabated entrainment begins beyond the zone of flow establishment, is driven by turbulent eddies, and depends on the radius and maximum velocity within the plume. Entrainment rates vary with the distributions of conditions across the plume and with the densimetric Froude number Fn. The number Fn characterizes whether the discharge behaves as a momentum-dominated jet ($Fn > 50$) or buoyancy-dominated plume ($Fn < 50$). In general, lower entrainment coefficients are found for higher Fn values[2]. A negatively buoyant jet would behave more as a plume after entrainment has reduced momentum, and plume conditions are likely to dominate with distance away from the discharge point regardless of initial Fn value.

[2] For convenience, symbols and abbreviations are listed in the Notation (Appendix G).

9. Five variables control the dynamic behavior of suspended sediment plumes: discharge rate Q, initial density difference between the dredged material and the ambient $\rho_m - \rho_o$, water depth D, current speed U, and gradient of the vertical ambient density $d\rho_o/dz$. A vertical density gradient can reduce plume density differences and entrainment, whereas currents enhance entrainment and lengthen the plume trajectory if descent is deflected from the vertical.

10. Analytical methods are available to estimate plume behavior and dilution during descent under various conditions. Vertically downward directed, round negatively buoyant plumes can be treated analytically. Negatively buoyant plumes discharged near the surface are dynamically analogous, though geometrically inverse to, buoyant plumes discharged at depth. The analytical procedures described by Fischer et al. (1979)[3] were used to estimate plume dilution and trajectory for homogeneous-quiescent, stratified, and flowing ambients. These procedures do not cover shallow conditions or include the combined effect of stratification and currents. Scalings used in this analysis were also used to classify the discharge according to a scheme developed by Jirka and Doneker (1991).

11. Fischer et al. (1979) present various plume scalings, graphical solutions for asymptotic solutions, and experimental data. Based on initial conditions, buoyancy B and momentum M parameters can be defined as:

$$B = g\,Q\,\frac{(\rho_m - \rho_o)}{\rho_o}, \qquad M = \frac{Q^2}{A} \tag{A1}$$

Length scales which indicate the influence of the ambient flow on the plume are:

$$Z_m = M^{1/2} / U, \qquad Z_b = B / U^3 \tag{A2}$$

where

g = acceleration of gravity, m/sec^2

A = area of discharge port, m^2

The normalized density stratification parameter $(-g/\rho_o)\, d\rho_o/dz$ was used to evaluate the effect of ambient density stratification on plume trajectory. The plume spreading rate db/ds (where b is plume radius and s is distance along the trajectory) is 0.11. The plume radius at the bed can be estimated from $b = b_o + 0.11s$, where b_o is the initial plume radius.

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[3]See references at the end of the main text.

12. To estimate the thickness, or height, of the underflow, h, it is assumed that velocity remains constant as the plume impinges on the bed and begins to spread horizontally. Therefore, the cross-sectional area of the plume normal to s equals the area of the underflow normal to flow at the perimeter of the plume and the underflow thickness h can be estimated as $1/2b$ as the plume reaches the bed.

Entrainment from an Underflow

13. Once the diluted dredged-material plume encounters the bed, it spreads along the bed and forms an underflow controlled by plume momentum, density difference with the ambient, shear stress from the overlying flow, viscous dissipation, and slope of the bed. Sediment in the underflow can be entrained into the overlying ambient flow under certain conditions. Entrainment will depend on the density or concentration and other characteristics of the underflow, geometry, and ambient flow conditions. Therefore, to estimate entrainment, the area and concentration (density) of the underflow must first be estimated. This section presents analyses of underflow spreading, settling, and entrainment for the purpose of estimating underflow sediment loss to the overlying flow.

Spreading

14. The thickness and rate of spreading of the underflow depend on plume condition at the end of convective descent, topography of the bed, ambient flow, and viscosity and settling of the underflow material. Previous spreading analyses (such as Koh and Chang 1973, Keulegan 1957) are based on the assumptions that the underflow is inviscid and implicitly that the Reynolds number for the layer is greater than a critical value for turbulent flow. DRP tests on cohesive dredged sediments similar to those at Tylers Beach have indicated that viscosities η at low shear rates increase with concentration to about 1 to 5 Pa-sec (or about 1,000 to 5,000 times the viscosity of water) as the sediment approaches a transition state (about 125 g/ℓ) where it develops a space-filling structure. The sediment will continue to settle and consolidate to higher densities, at a very slow rate, and the corresponding viscosities then climb rapidly to 10's and 100's of Pa-sec. Viscous effects are important at underflow concentrations of 50 g/ℓ or greater.

15. A set of simple viscous spreading laws was developed for this study. Two cases are considered analytically: (a) spreading of a fixed-volume underflow, and (b) spreading with a constant underflow inflow rate. In both cases it was assumed that the bed is horizontal, viscosity is constant, the overlying flow exerts negligible shear stress on the underflow, and that the spreading is radial

with respect to the location where the plume impinges on the bed. These assumptions, and restrictions they imply, could be eliminated in future work. Underflow spreading was evaluated assuming that the underflow is laminar and that the viscosity is much greater than water, but low enough so that material will have a level top surface. Figure A2 shows a schematic of the two cases (A and B) and the underflow characteristics, which include uniform underflow thickness h, depth-mean speed $U_u(r)$, radial distance from the underflow center r, spreading rate at the outer perimeter of the underflow U_u, r at the outer perimeter R, inflow rate Q_u, and volume V.

16. Spreading and shear stress dissipation are assumed driven by pressure caused by the density difference between the underflow and the ambient. The pressure at the edge of the underflow varies with distance from the bed, and averages $g(\rho_m - \rho_o)h/2$. The total force F_ρ acting on the area of the edge is:

$$F_\rho = \pi g (\rho_m - \rho_o) R h^2 \tag{A3}$$

where R is the radius of the underflow. The underflow shear stress depends on $U_u(r)$ and, therefore, varies along the radius of an expanding underflow layer. Because the underflow is assumed laminar, local shear stress can be calculated as $2U_u(r)\eta/h$. For a constant volume underflow, the area-weighted average shear stress occurs at $0.79U_u$ exerting a total force F_t over the bottom of the underflow as:

$$F_t = 1.59\pi\eta \frac{U_u R^2}{h} \tag{A4}$$

Thus, the spreading rate of a slug of material volume V can be estimated by substituting $R = (V/\pi h)^{1/2}$ to give:

$$U_u = \frac{1.11 g (\rho_m - \rho_o) h^{7/2}}{\eta V^{1/2}} \tag{A5}$$

According to this analysis, the underflow will continue to spread at decreasing speeds because the processes which might halt spreading, such as settling and/or gelling, are not included.

17. For the case of an underflow with a constant inflow at its center, the area-average shear stress occurs at $R/2$. The underflow speed at distance r from the underflow center can be estimated from the continuity expression $U_u(r) = Q_u / 2\pi r h$. Substituting this expression and $V = \pi R^2 h$ into Equation A5, the thickness of the underflow can be estimated as:

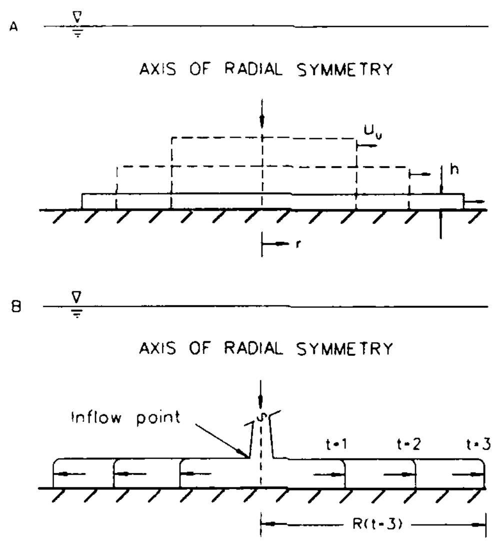

Figure A2. Schematic of underflow characteristics

$$h = \frac{\eta \, Q_u}{\pi \, g(\rho_m - \rho_o)^{1/4}} \tag{A6}$$

It should be noted that no field data are known to exist with which to compare and verify Equations A3 to A6.

<u>Settling</u>

18. Settling increases characteristic underflow concentration by consolidation over time. The underflow at Tylers Beach was in the hindered-settling range of concentration according to the results presented in paragraph 60 of the main text: therefore, the suspension settled as a mass. Sediment particles do not deposit on the bed individually under these conditions, and a deposit was formed as the underflow eventually consolidated.

19. As concentrations of cohesive suspensions increase, a concentration is reached where settling velocities became hindered by interparticle contact, and at slightly higher concentrations settling fluxes (the product of settling speed and concentration) also begin to decrease. At these higher concentrations, suspensions settle as a mass and form a distinct layer. Settling in the hindered-settling concentration range can be approximated by:

$$W_s = W_i \, (1 - k \, C)^5 \qquad \text{(A7)}$$

where W_i is a maximum settling speed, k is the inverse of the fully settled concentration (about 0.002 ℓ/g), and C is the suspension concentration (g/ℓ) (Richardson and Zaki 1954).

20. Figure A3 is an example of these relationships for cohesive sediments from Corpus Christi Harbor, Texas, and demonstrates how rapidly W_s decreases with concentration in the dense-suspension concentration range. Unhindered settling speed W_s is also related to concentration and is shown in Figure A3 for comparison to Figure 28 presented in the main text. Because W_s decreases with concentration, progressively longer times are required to settle and consolidate for progressively higher concentrations. The zone settling test results presented in paragraph 60 of the main text indicated that Tylers Beach sediment slurries will settle to about 125 g/ℓ solids content relatively rapidly, depending on the thickness of the suspension.

Entrainment

21. Entrainment of one fluid layer by another turbulent fluid layer is common to many geophysical situations, such as those described by Turner (1986). The concept of entrainment was originally proposed for round, buoyant jets by Morton, Taylor, and Turner (1956). In the case of a quasi-stationary dredged material layer overlaid by a turbulent layer, entrainment is affected by density differences, unlike the case of plume entrainment. The rate of entrainment of dense layers in general depends on a bulk Richardson number Ri relating the velocity of the overlying flow to the buoyant forces at the underflow interface:

$$Ri = \frac{g(\rho_m - \rho_o) \, D}{\rho_o U^2} \qquad \text{(A8)}$$

where D is the water depth. Experimental results and entrainment laws have been previously developed for simple dense layers recently developed for clay suspensions (Srinivas and Mehta 1990 and Scarlatos and Mehta 1990). A simple power-law expression for the non-dimensional buoyancy flux (Q^*) based on data developed under the DRP and consistent with other high-Ri entrainment laws (Christodoulou 1986) is:

$$Q* = K\,Ri^{-3/2} \tag{A9}$$

where $Q^* = dm/dt\ /\ U(\rho_m - \rho_o)$, dm/dt is the mass flux per unit area out of the underflow, and the coefficient K is proposed here to have the value of 0.0158. Buoyancy flux in the case of a sediment underflow is subject to the constraints that are presented next.

22. Entrainment of underflow sediment material differs from that of a simple dense fluid in that the fluid mud material may have appreciable viscosity, may be formed in a thin layer, and is composed of settleable solids. The effect of settling flux on entrainment has been observed but not studied in detail. To include this effect, entrainment is expressed here as the sum of upward-vertical turbulent and settling flux components. When a turbulent layer entrains a dense layer, a stably-

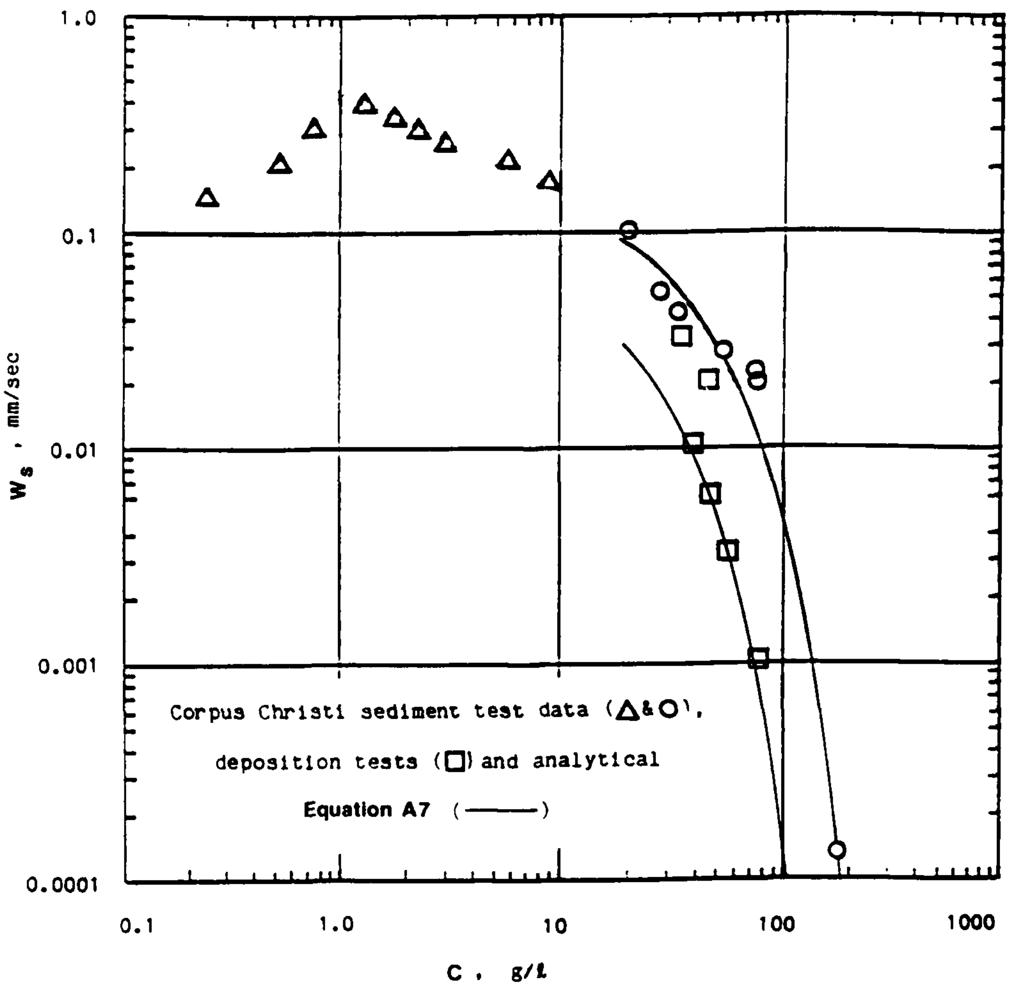

Figure A3. Example of cohesive sediment settling relationships

stratified interfacial layer develops at the top of the dense layer. For relatively large density differences and Ri, entrainment starts with large-scale turbulent motions impinging on the interfacial layer, creating buoyancy recoils and/or breaking internal waves (E and Hopfinger 1986, Turner 1986, and Linden 1973). Density striations develop within the layer and filaments or wisps are pulled from the top of the interfacial layer. Small-scale turbulence and, eventually, molecular diffusivity are involved in completing the mixing of material into the turbulent layer. The development of density structure in the interfacial layer, and flux of material from it, are opposed by the settling of solids. Narimousa and Fernando (1987) found that an additional stable intermediate layer formed in the case of dense-fluid entrainment at high Ri. The existence of this layer would allow solids to settle and reform fluid mud. Since fluid mud is the subject here and concentrations in an intermediate zone would be near, and span, the maximum settling flux, it is proposed that the quantity $(W_sC)_{max}$ be used to correct entrainment flux E for settling. Thus,

$$E = \overline{W'C'} - (W_sC)_{max}, \qquad \overline{W'C'} > (W_sC)_{max} \tag{A10}$$

where $\overline{W'C'}$ is the upward-vertical turbulent interfacial flux, W is vertical current, primes denote fluctuating components, and the overbar denotes time averaging.

23. General viscosity effects on entrainment were examined by Campbell and Turner (1986) but they have not been studied in the case of fluid mud. On theoretical grounds, Campbell and Turner (1986) proposed that the viscosity effect depends on the parameters $k_{1,2} = [\rho_m UD/\eta]_{1,2}$. They performed tests on a vertical jet where the ratios of fluid viscosities were as great as 400 to 1, and documented conditions under which entrainment was completely suppressed (k_1) and unaffected by viscosity (k_2). Viscosity constraints can be stated:

$$\overline{W'C'} = KU(\rho_m - \rho_o)\, Ri^{-3/2}, \qquad \frac{\rho_m UD}{\eta} > k_2 \tag{A11a}$$

$$\overline{W'C'} = \left[\frac{\rho_m UD - k_1\eta}{(k_2 - k_1)\eta}\right] KU(\rho_m - \rho_o) Ri^{-3/2}, \qquad k_1 < \frac{\rho_m UD}{\eta} < k_2 \tag{A11b}$$

$$\overline{W'C'} = 0, \qquad \frac{\rho_m UD}{\eta} < k_1 \tag{A11c}$$

where the values $k_1 = 7$ and $k_2 = 70$ from Campbell and Turner (1986) were assumed for this study.

24. The effect of small *h/D* on entrainment of an underflow has not been studied, but some inferences can be drawn from other investigations. In most experiments, the dense layer thickness was of the same order as the turbulent layer. Under these conditions the interfacial layer has been found to be about 0.06 *D* thick and only weakly dependent on *Ri*. The amplitudes of disturbances on the interfacial layer have been found to be of similar dimension, although more dependent on *Ri* (Wolanski 1972, Turner 1986, Narimousa and Fernando 1987, and Christodoulou 1986). Within 0.1 *D* of a solid boundary, vertical turbulent fluctuations decrease. Turbulent eddies do not often penetrate into the center of the interfacial layer (McDougall 1979). The effect on entrainment of *h/D* having a value of less than 0.1 is not known; however, it is plausible that entrainment would be reduced due to decreased interfacial layer disturbance amplitudes.

Passive Dispersion

25. Material which has been stripped from the descending plume or entrained from the underflow constitutes a localized source for sediments to the ambient estuarine suspension and therefore is subject to passive transport, dispersion, and redeposition. The dispersion is passive in the sense that it is not hindered by the dynamics of either the descending plume or the underflow. Dispersed sediments will behave as other similar sediments in suspension with respect to vertical mixing, settling, and deposition. Passive dispersion depends on the capacity of natural vertical turbulent diffusion to mix and transport material into the flow, which in turn depends on the level of turbulent mixing in the flow and the settling properties of the material.

26. A two-dimensional, vertically averaged analytical model of the dispersion and deposition of a suspended sediment cloud was used to evaluate passive dispersion (Teeter 1988). The model includes the effects of sediment deposition and a steady current. The model equation is:

$$C = \frac{Q_s}{2D\,V_s\,X} \exp\left[-\frac{U_x\,Y}{V_s\,X} - \frac{P\,W_s\,X}{D\,U_x}\right] \tag{A12}$$

where

C = depth-averaged cloud concentration at X and Y

X and Y = horizontal coordinates in the downstream and cross-stream directions, respectively

Q_s = sediment release rate

U_x = depth-averaged current speed in the X-direction

V_s = dispersion velocity in m/sec taken as $0.11\ U_x$

P = depositional probability taken as $1 - \tau/\tau_{cd}$ where τ_{cd} is the critical shear stress for deposition, τ is bed shear stress, and $\tau < \tau_{cd}$

and meter, gram, and second units are used. The diffusion velocity used in the model formulation introduces length-scale dependence into computed dispersion. The passive dispersion model assumes that W_s is constant and, therefore, should be applied where concentrations are below about 200 mg/ℓ.

27. The passive dispersion model was used to estimate dispersion of material from the vicinity of the Tylers Beach discharge point (within 225 m), and also used in an inverse mode to estimate the entrainment rate, in g/sec, of material from the vicinity of the discharge.

Results for Tylers Beach Pipeline Discharge

28. Burwell Bay is a shallow area of the James River Estuary with numerous active oyster grounds that has a mean tide range of 0.73 m. The dredged material was transported through a 0.3-m-diam discharge line ending in a vertically downward section (a tremie) and a diffuser located 4 m below tide level. Figure A1 shows a schematic of the discharge termination and the resulting sediment plume and underflow.

Plume descent

29. The discharge is inferred to behave as a negatively buoyant plume. The density of two dredged material samples averaged 1,104 kg/m^3 (154 g/ℓ solids content). The density of the ambient water was about 1,006 kg/m^3. The conical-shaped diffuser on the end of the discharge line had twice the area of the 0.3-m-diam discharge line, or about 0.15 m^2. The discharge rate was about 0.28 m^3/sec. Thus, based on available information, the Fn of the discharge is estimated to be about 4.

30. The total sediment discharge under the above conditions was 13.1×10^6 kg dry weight over a 3.5-day period, for an average rate of 43×10^3 g/sec. The reported 13.7×10^3-m^3 dredged volume would amount to 6.6×10^6 kg assuming the average moisture content of the disposal site was

representative of the dredged site. The differences in the magnitudes of these two estimates of kilograms of sediment dredged could be due to uncertainties in values used in the calculations.

31. Scaling for momentum Z_m was 2.8 m and for buoyancy Z_b was 14.9 m (Equations A1 and A2). Length-scale analysis showed that, within the classification scheme of Jirka and Doneker (1991), the discharge was a vertical shallow-water flow with strong momentum dominated by buoyancy. The plume contacted the bed with strong momentum. The dense plume was expected to be stable with respect to the ambient flow, and to form a stratified spreading layer at the bed.

32. Since the 4-m distance between the diffuser and the bed equates to only about 10 discharge port diameters, analytic plume models may be unreliable. As discussed in paragraph 7, discharges require about six diameters to establish similar transverse velocity and concentration distributions. Experimental data on dilution at small distances from the discharge port (Fischer et al. 1979, Figure 9.6) indicate that a dilution of about four would be reached as the plume reached the bed.

33. Other analytical procedures which include the effect of currents (Fischer et al. 1979, page 362) were used to estimate the dilution of the plume as it reached the bed. Predicted dilution was about the same as for the no-current case (approximately 4). The plume radius and vertical speed at the bed were estimated to be 0.38 m and 2.7 m/sec, respectively. Over the distance between the discharge point and the bed, the procedures indicated that currents had little effect on plume trajectory. Calculations based on stratification indicated that the minimum unrestricted descent depth (assuming no bed interference and constant stratification) would be over 7 m. As indicated previously, these calculations do not include the combined effects of stratification and currents.

34. The initial thickness of the underflow is expected to equal one half the plume radius (see paragraph 12), under the assumption that momentum and flow speed are preserved as the plume impinges on the bottom and begins to flow horizontally along the bottom. The thickness of the underflow was expected to equal about 0.19 m. The initial radial flow in the underflow would thus be about 2.7 m/sec.

Underflow spreading and entrainment into the overlying flow

35. The starting point for the underflow is the plume as it impinges on the bottom. Given a dilution of four, density of 1,031 kg/m^3 (39 g/ℓ), speed of 2.7 m/sec, thickness of 0.19 m, and assumed viscosity of 0.2 Pa-sec, the initial Reynolds Number is computed by:

$$Re = \frac{4\rho_m h\ U_u}{\eta} \tag{A13}$$

In this case, the *Re* for the underflow was about 10,000 and above the transition to turbulent flow. The underflow decelerates rapidly with spreading distance near the discharge point. If the underflow thickness remained constant, *Re* varied inversely with radius and would have dropped to 750 at 5 m horizontal distance from the discharge point. Therefore, the underflow began as a turbulent flow, but is predicted to have rapidly transitioned to laminar flow.

36. Another estimate of underflow thickness was calculated as 0.16 m assuming η = 1 Pa-sec, Q_u = 1.12 m^3/sec, and ρ_m = 1,084 kg/m^3 using Equation A6. Using this thickness, the spreading rate was then calculated by the continuity expression presented in paragraph 17 giving the results listed in Table A1. According to this analysis, the spread to a 100-m radius would be achieved in about 1 hr.

Table A1

Calculated Underflow Thickness and Spreading Rates

Radius m	U_u m/sec	Spreading Time sec
10	0.11	0
20	0.057	120
30	0.038	330
50	0.0228	1,020
75	0.0152	2,335
100	0.0114	4,214

37. Fixed-volume underflow spreading analysis was used to estimate the radius and thickness of the material spread before consolidation effects on viscosity would reduce further spreading by half. Fixed-volume spreading evaluation was based on a density of 1,084 kg/m^3 (or solids content of 125 g/ℓ). Settling would consolidate the diluted dredged material to this state within hours. The volume of underflow was assumed to be 55x10^3 m^3 or about a bulking factor of 4 over the in situ material reported dredged. Spreading was started at an artificially high thickness. Table A2 presents fixed-volume viscous spreading rates starting with a thickness of 1 m and a radius of 132 m as

Table A2

Fixed-Volume Viscous Spreading Rates

Thickness m	Radius m	Time sec	U_u m/sec
1.0	132	0	3.63
0.5	187	50	0.32
0.3	242	462	0.054
0.2	296	2,083	0.013
0.15	348	7,925	0.0047
0.1	418	32,338	0.0011
0.075	483	117,470	0.0004
0.05	592	535,170	0.0001

computed with Equation A5. These results suggest that the underflow would spread to a radius of about 450 m with a thickness of a little less than 0.1 m in about a day. A one-day settling time would probably increase viscosities another order of magnitude and effectively stop further spreading. Note that the final deposit thickness formed by the uniform-thickness underflow at R = 420 m would be only about one-fourth as large as shown in Table A2, or about 0.025 m, due to the ultimate consolidation of the deposit to the average moisture content of bed material samples (172 percent or 480 g/ℓ solids content).

38. Underflow spreading analysis for constant discharge and fixed-volume cases indicated that material of relatively low concentration (< 125 g/ℓ) might spread to 100 m distance from the discharge point, and that denser material might ultimately spread to 450 m.

Entrainment

39. Underflow entrainment was calculated based on 100-m spreading of progressively denser material. Entrainment is not expected to occur from underflow with concentrations in excess of 125 g/ℓ. Results overestimated entrainment, as will be discussed later, but are presented for discussion and to illustrate certain features of the calculations.

40. Using data from the zone settling test and constant-discharge spreading predicted for distances, lower-limit entrainment rates were calculated using Equations A10 and A11a for the current speeds observed at Station 4 and are displayed in Table A3. Because the viscous characteristics of the material are unknown, viscous effects were omitted from the calculations. For any individual calculation in which the Ri was greater than 100, E was assumed to be 0.0.

Passive dispersion

41. The suspended sediment samples taken at the project site were used to estimate the magnitude of suspended sediment dispersion from the vicinity of the discharge point. Station 4 was the only sampling station at which suspended sediment was increased over background levels by the discharge of dredged material. That increase was about 10 mg/ℓ average, with an increase of about 30 mg/ℓ in the peak concentration, based on 51 observations. Station 4 was located about 225 m from the discharge point (see Figure 22 in the main text).

42. Equation A12 was solved assuming a 100-g/sec sediment source and a distance of 225 m. Suspended sediment concentrations and fluxes were calculated using frequency distributions for current speed and depositional characteristics (settling velocity and assumed depositional probabilities are defined in paragraph 26). Four sediment fractions and four current speed ranges were used to describe distributions. The frequency distribution of current speed at Station 4 and low-concentration settling speed distribution were used. Results are shown in Table A4. Results include movement of material beyond 225 m for the various sediment fractions, center-line or peak concentration increases, and average increases within 65 m lateral distance of the center line (estimated to be the lateral extent of the cloud at 225 m downstream). The calculations indicate that movement of suspended material

Table A3

Calculated Entrainment Rates*

	Underflow Area (Radius, m)			
	0-50	50-75	75-100	
	Assumed Underflow Concentration, g/ℓ			
U, m/sec	68	94	125	Weighted Total kg/sec
0.08	0.0	0.0	0.0	0.0
0.23	0.0	0.0	0.0	0.0
0.38	0.5	0.0	0.0	0.7
0.53	8.0	7.0	6.6	13.7
Weighted Average, kg/m^2	0.5	0.4	0.3	

*Entrainment rate $E = 10^{-3}$ kg/m^2/sec.

beyond 225 m was 85 percent of the discharge rate, based on an average weighted by the occurrence of current speed and sediment fraction. Average concentration over the central 65-m plume width and peak concentration on the plume center line were calculated as 3.5 and 5 mg/ℓ, respectively.

43. Results were compared with measured suspended sediment increases at Station 4. Because the model linearly relates concentration to the source sediment dispersion rate, ratios between predicted and observed cloud concentrations (increases over ambient) can be applied to the assumed sediment source to estimate the magnitude of the actual sediment dispersion rate. The average plume concentration is a more reasonable estimate to compare with field data because Station 4 is not directly down-current from the discharge point. Based on the total weighted-average concentration, the release from near the discharge point is estimated to be 300 g/sec. The highest concentrations were predicted to occur at low current speeds, even though the most rapid depositing sediment fraction has a lower escape probability for this current speed (see Table A4).

Discussion of Fluid Mud Entrainment

44. A total average entrainment of 14 kg/sec underflow material was calculated by the analysis presented in the last section, compared to a known discharge rate of 43 kg/sec at the discharge point. Observed dispersion rates at Station 4 were only about 2 percent of those predicted by the entrainment analysis. Predicted entrainment rate varied strongly with current speed and was highest at highest currents. Therefore, not only was the magnitude of entrainment overestimated, but the trend of entrainment versus current speed also does not match the field observation (Figure A4). Exact causes for the discrepancies are not yet known, but they may have been caused by coefficients being set to values developed for lower viscosity material, omission of viscosity effects from entrainment analysis, overestimated current speeds, or the small thickness of the underflow. More study of the entrainment process is indicated.

45. The thickness of the underflow may have reduced entrainment. Previous laboratory experiments with both dense fluids and sediment suspensions have shown that the thickness of the interfacial stable layer is about 0.05 to 0.07 times D (Narimousa and Fernando 1987 and Wolanski 1972). The underflow thicknesses h predicted based on plume and underflow spreading analyses were about 0.03 D. This small h/D could have damped interfacial wave amplitudes, accelerations, and hence cusp formation and interfacial flux $\overline{W'C'}$.

Table A4

Passive Dispersion of Dredged Material

for 100-g/sec Release Rate 225 m Downstream of Release*

			U, m/sec			
			0.08	0.22	0.38	0.53
			Frequency of Occurrence			
W_s, mm/sec	τ_{cd}, N/m^2**	Frequency	0.19	0.57	0.19	0.05
			Fraction Escaping, g/sec			
0.45	0.100	0.20	13.87	92.84	92.84	92.84
0.16	0.100	0.30	47.23	92.84	92.84	92.84
0.09	0.050	0.20	85.33	92.84	92.84	92.84
0.02	0.050	0.20	85.33	92.84	92.84	92.84
Weighted Totals, Average g/sec			10.08	52.92	17.64	4.64
			Average Concentration, mg/ℓ			
0.45	0.100	0.20	3.98	0.92	0.53	0.38
0.16	0.100	0.30	13.55	0.92	0.53	0.38
0.09	0.050	0.30	18.23	0.92	0.53	0.38
0.02	0.050	0.20	24.49	0.92	0.53	0.38
Weighted Totals, Average mg/ℓ			2.89	0.52	0.10	0.02
			Peak Concentration, mg/ℓ			
0.45	0.100	0.20	5.67	1.31	0.76	0.54
0.16	0.100	0.30	19.32	1.31	0.76	0.54
0.09	0.050	0.30	25.98	1.31	0.76	0.54
0.02	0.050	0.20	34.90	1.31	0.76	0.54
Weighted Totals, Average mg/ℓ			4.12	0.75	0.14	0.03

*See text for explanation

**$P = 1 - \tau/\tau_{cd}$ where τ_{cd} is the critical shear stress for deposition, τ is the bed shear stress, and $\tau < \tau_{cd}$.

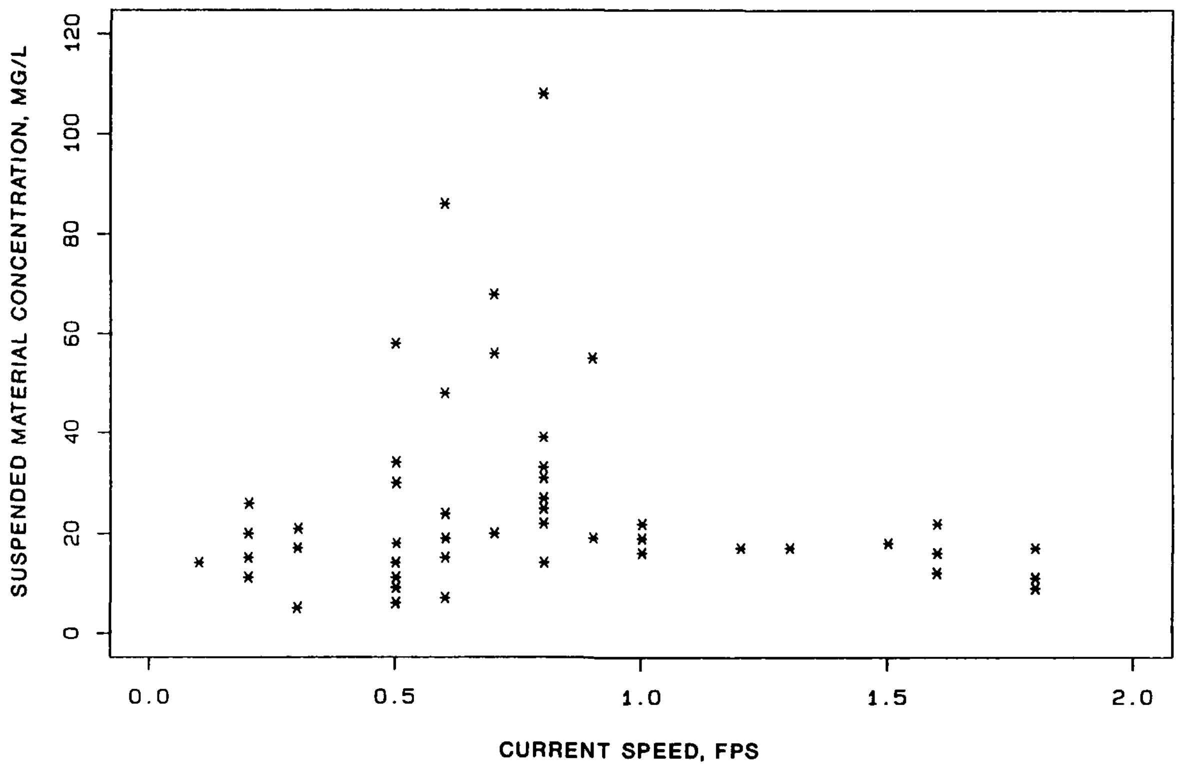

Figure A4. Field observations of concentration versus current speed

APPENDIX B: SUSPENDED MATERIAL CONCENTRATION, SALINITY, AND CURRENT SPEED AND DIRECTION[1]

This appendix contains tables listing measurements taken from both acoustic and in situ sampling devices. Table B1 gives measurements of depth, temperature, and salinity from the conductivity, temperature, and depth (CTD) recorder used by Team 1. Table B2 gives measurements of depth, temperature, and salinity from the CTD sensor and tide gage placed at Rescue Marina by Team 2. Table B3 gives measurements of suspended material, salinity, and current speed and direction taken by Team 1 from all stations. Suspended material concentration was obtained from laboratory analysis of water samples; current information was obtained from the 2.4-MHz acoustic system; and salinity values are from laboratory analysis of water samples. Table B4 gives Team 2 measurements of suspended material, salinity, and current speed and direction. An additional list of salinity values in Table B4 was taken with a salinometer, and current information was measured with a propeller velocity meter and magnetic directional indicator. Suspended material concentration and salinity values from laboratory analyses of samples taken by the automatic water samplers are given in Table B5.

[1]Written by Mscs. Michelle M. Thevenot and Terri L. Prickett.

Table B1

CTD Depth, Temperature, and Salinity (Team 1)

Date	Station No.	Sample Time EDT*	Depth ft**	Temperature deg C	Salinity ppt
			Background		
09/29	1	1015	1.8	21.79	--
			5.3	21.65	--
			9.2	21.58	--
	2	1027	1.2	21.10	--
			7.7	21.63	--
			12.1	21.63	--
	3	1035	1.8	21.79	--
			7.4	21.64	--
			13.6	21.62	--
	4	1042	1.8	21.83	--
			7.1	21.65	--
			13.3	21.60	--
	5	1057	12.4	21.59	--
			5.6	21.60	--
			1.2	21.70	--
	6	1105	1.2	21.63	--
			6.5	21.58	--
			12.4	21.57	--
	7	1116	1.5	21.75	--
			6.5	21.64	--
			12.4	21.61	--
	8	1124	1.5	21.88	--
			6.5	21.67	--
			12.1	21.68	--
	9	1130	1.5	21.95	--
			5.9	21.70	--
			12.1	21.70	--
	10	1137	1.5	21.96	--
			6.2	21.78	--
			12.1	21.70	--
	11	1145	6.8	22.11	--
			12.1	21.73	--
	12	1153	1.8	21.08	--
			9.5	21.84	--

(Continued)

*Eastern Daylight Time.
**Surface sample obtained 1 ft below water surface, bottom sample obtained 1 ft above the river bed.

(Sheet 1 of 7)

Table B1 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Temperature deg C	Salinity ppt
			Background		
09/29			12.1	21.76	--
	13	1202	1.5	22.35	--
			7.4	21.93	--
			13.3	21.81	--
	14	1212	1.5	22.07	--
			5.6	22.01	--
			8.0	22.02	--
	15	1219	1.5	22.07	--
			5.0	22.12	--
			14.8	22.11	--
	16	1228	0.9	22.65	--
			7.1	22.10	--
			12.4	22.09	--
	17	1236	1.8	22.10	--
			8.0	22.09	--
			14.2	22.08	--
	18	1242	1.5	21.76	--
			5.6	22.10	--
			14.5	22.09	--
	19	1249	1.5	22.00	--
			3.6	22.08	--
			8.3	22.07	--
	21	1419	1.2	22.20	12.12
			5.6	22.07	12.21
			10.1	22.07	12.21
	22	1425	1.5	22.48	11.81
			10.9	22.40	11.87
			19.5	22.36	12.00
	23	1440	1.5	22.14	12.28
			5.3	21.70	12.57
			7.7	21.68	12.55
	24	1451	1.2	21.58	12.57
			5.0	21.70	12.56
			8.0	21.63	12.58
	25	1456	1.5	21.58	12.67
			5.0	21.58	12.67
09/29			8.6	21.56	12.69

(Continued)

(Sheet 2 of 7)

Table B1 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Temperature deg C	Salinity ppt
			Background		
09/29	26	1525	1.2	21.70	12.93
			5.9	21.58	13.01
			10.9	21.43	13.05
	27	1535	5.9	21.50	12.84
			13.6	21.24	13.10
	28	1545	1.5	21.69	12.52
			7.4	21.36	12.86
			13.6	21.09	13.08
	29	1552	1.5	21.92	12.54
			10.3	21.75	12.79
			18.6	21.52	13.06
	30	1558	1.5	21.81	12.70
			10.9	21.60	12.93
			16.8	21.40	13.14
	31	1608	1.5	21.65	12.90
			10.1	21.57	12.99
			13.9	21.51	13.16
	32	1620	1.5	21.71	12.91
			7.4	21.64	12.99
			13.3	21.61	13.14
	33	1633	1.5	21.65	12.95
			8.0	21.64	12.99
			14.2	21.55	13.02
09/30	1	1222	1.5	22.02	11.35
			5.3	21.93	10.97
			9.5	21.22	11.25
	4	1239	1.8	22.29	11.09
			8.0	21.89	11.11
			13.3	21.53	11.27
	6	1249	1.8	22.26	10.43
			6.2	22.14	10.79
			11.8	21.70	11.21
	8	1257	2.1	22.32	10.18
			7.1	22.05	10.79
			11.8	21.73	11.21
	10	1306	1.8	22.48	9.92
09/30			6.2	22.23	10.21

(Continued)

(Sheet 3 of 7)

Table B1 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Temperature deg C	Salinity ppt
			Background		
09/30			10.3	21.82	11.09
	13	1316	2.1	22.43	9.70
			5.6	22.33	9.81
			12.4	21.82	10.60
	19	1330	1.8	21.99	11.57
			3.0	22.01	11.56
			4.7	21.97	11.53
	32	1336	1.8	22.01	11.47
			12.4	21.96	11.47
			22.3	21.95	11.45
	35	1350	1.8	22.33	11.32
			7.4	22.25	11.32
			13.6	22.26	11.35
	33	1359	1.8	21.94	11.75
			6.5	21.90	11.76
			13.3	21.88	11.78
	31	1410	1.8	21.92	11.81
			8.9	21.84	11.85
			16.8	21.82	11.85
	30	1419	1.8	21.90	11.51
			8.6	21.80	11.56
			21.6	21.86	11.69
	28	1431	1.5	21.89	11.64
			7.1	21.78	11.65
			13.6	21.54	11.70
	27	1441	1.8	21.71	11.99
			7.4	21.71	12.01
			13.9	21.69	12.00
	23	1458	2.1	21.83	12.49
			4.4	21.88	12.48
			8.6	21.87	12.47
	21	1504	2.1	21.88	12.20
			10.3	21.89	12.57
			16.3	21.89	12.56
	17	1519	1.8	21.83	12.70
			8.0	21.82	12.72
09/30			14.2	21.82	12.71

(Continued)

(Sheet 4 of 7)

Table B1 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Temperature deg C	Salinity ppt
			Background		
09/30	14	1528	2.1	21.41	12.87
			6.2	21.68	12.79
			11.2	21.65	12.79
	1	1620	1.5	21.51	12.48
			7.4	21.49	12.50
			10.9	21.47	12.49
	4	1630	1.8	21.53	12.54
			7.7	21.54	12.52
			14.5	21.51	12.51
	6	1645	1.5	21.63	12.61
			6.8	21.62	13.22
			13.0	21.71	13.61
	8	1650	1.8	21.69	13.14
			6.5	21.68	13.44
			13.3	21.70	13.72
	10	1656	1.5	21.65	13.13
			5.9	21.70	13.46
			12.7	21.69	13.60
	13	1704	1.8	21.76	13.16
			7.4	21.72	13.35
			13.9	21.65	13.43
10/01	32	1030	1.5	21.86	12.14
			10.9	21.57	13.03
			23.3	21.52	12.98
			20.7	21.49	13.33
	19	1049	1.2	22.15	10.69
			3.0	21.81	11.76
			4.4	21.75	12.08
	9	1057	2.4	21.79	11.92
			5.3	21.76	12.04
			10.9	21.74	12.30
	32.5	1101	1.5	22.08	10.69
			7.4	21.68	12.33
			13.3	21.56	13.05
	18	1105	5.3	21.74	11.55
			11.2	21.66	12.21
10/01	7	1154	1.5	21.98	11.10

(Continued)

(Sheet 5 of 7)

Table B1 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Temperature deg C	Salinity ppt
			During Dredged Material Placement		
10/01			2.7	21.78	11.43
			12.1	21.66	12.58
	31.5	1159	1.0	21.91	11.37
			9.5	21.82	11.63
			19.5	21.70	12.14
	20	1203	2.4	22.14	11.07
			4.4	22.12	11.05
	21	1214	1.5	22.78	10.61
			12.4	21.96	11.23
			22.5	21.71	12.24
	31	1218	1.5	22.70	10.59
			13.3	21.77	11.72
			16.8	21.71	12.03
	21.5	1231	1.5	22.18	10.48
			4.7	22.31	10.89
	91	1250	1.8	22.61	10.48
			14.2	21.76	11.93
			18.3	21.77	12.13
	30.5	1254	1.5	22.44	10.73
			8.6	22.22	11.12
			20.1	21.68	12.31
	22	1259	1.5	22.05	10.50
			5.0	22.39	10.84
			10.1	22.12	11.21
	72	1438	1.8	22.64	11.83
			5.0	21.95	12.36
			9.5	21.88	12.49
	22	1444	3.3	22.53	11.93
			5.0	22.16	12.15
	21	1449	1.8	22.35	11.90
			13.3	22.00	12.12
			25.7	21.58	12.78
	19	1456	1.2	22.33	12.09
			3.0	22.31	12.12
			5.6	22.33	12.11
	17	1504	1.5	22.34	11.97
10/01			9.2	22.33	12.21

(Continued)

(Sheet 6 of 7)

Table B1 (Concluded)

Date	Station No.	Sample Time EDT	Depth ft	Temperature deg C	Salinity ppt
		During Dredged Material Placement			
10/01			13.9	22.39	12.25
	8	1804	1.2	21.94	12.76
			6.8	21.92	13.42
			13.3	21.92	13.93
	32	1814	1.5	21.91	13.18
			8.0	21.91	13.66
			14.8	21.89	13.81
	32.5	1819	1.2	21.91	13.71
			8.3	21.93	13.90
			17.1	21.93	14.03
	9	1825	1.2	21.81	13.17
			7.4	21.91	13.71
			13.3	21.91	13.76
	18	1831	1.8	21.84	14.23
			4.7	21.85	14.23
			8.9	21.85	14.22
	19	1836	1.2	21.97	14.29
			3.3	21.97	14.28
			5.6	21.97	14.28

(Sheet 7 of 7)

Table B2

Temperature, Salinity, and Depth Taken at Rescue Marina

Date	Sample Time EDT*	Temperature deg C	Salinity ppt	Depth ft
		Background		
09/29	1915	24.90	14.4	5.844
	1930	23.02	14.9	5.678
	1945	22.05	15.2	5.530
	2000	21.63	15.3	5.384
	2015	21.47	15.3	5.253
	2030	21.42	15.2	5.128
	2045	21.42	15.2	5.027
	2100	21.42	15.1	4.940
	2115	21.44	15.1	4.867
	2130	21.45	15.0	4.801
	2145	21.47	15.0	4.745
	2200	21.48	14.9	4.710
	2215	21.49	14.9	4.681
	2230	21.50	14.7	4.670
	2245	21.49	14.7	4.686
	2300	21.48	14.6	4.692
	2315	21.46	14.7	4.712
	2330	21.42	14.7	4.774
	2345	21.40	14.7	4.840
09/30	0000	21.39	14.7	4.924
	0015	21.36	14.7	5.010
	0030	21.33	15.0	5.123
	0045	21.29	15.1	5.246
	0100	21.24	15.2	5.383
	0115	21.19	15.2	5.517
	0130	21.12	15.2	5.667
	0145	21.01	15.3	5.825
	0200	20.87	15.3	5.974
	0215	20.76	15.4	6.119
	0230	20.68	15.4	6.247
	0245	20.57	15.4	6.367
	0300	20.42	15.5	6.476
	0315	20.28	15.6	6.568
	0330	20.19	15.6	6.644

(Continued)

*Eastern Daylight Time.

(Sheet 1 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		Background		
09/30	0345	20.14	15.7	6.703
	0400	20.12	15.7	6.742
	0415	20.11	15.7	6.750
	0430	20.10	15.7	6.738
	0445	20.09	15.7	6.709
	0500	20.07	15.5	6.649
	0515	20.08	15.5	6.579
	0530	20.08	15.5	6.492
	0545	20.03	15.6	6.391
	0600	19.95	15.5	6.314
	0615	19.88	15.5	6.170
	0630	19.90	15.5	6.040
	0645	19.94	15.5	5.931
	0700	20.00	15.5	5.793
	0715	20.06	15.4	5.692
	0730	20.15	15.4	5.577
	0745	20.23	15.3	5.465
	0800	20.30	15.2	5.368
	0815	20.35	15.1	5.273
	0830	20.39	15.0	5.192
	0845	20.43	15.0	5.110
	0900	20.48	14.9	5.039
	0915	20.51	14.9	4.970
	0930	20.55	14.8	4.921
	0945	20.58	14.8	4.873
	1000	20.60	14.8	4.840
	1015	20.61	14.8	4.806
	1030	20.60	14.8	4.781
	1045	20.60	14.8	4.775
	1100	20.61	14.8	4.795
	1115	20.63	14.8	4.839
	1130	20.64	14.9	4.894
	1145	20.65	14.9	4.970
	1200	20.65	15.0	5.070
	1215	20.61	15.1	5.194
	1230	20.56	15.2	5.331
	1245	20.49	15.3	5.483

(Continued)

(Sheet 2 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		Background		
09/30	1300	20.47	15.4	5.637
	1315	20.53	15.5	5.808
	1330	20.62	15.5	5.982
	1345	20.69	15.6	6.141
	1400	20.74	15.6	6.304
	1415	20.79	15.6	6.460
	1430	20.84	15.7	6.608
	1445	20.91	15.7	6.738
	1500	21.02	15.7	6.854
	1515	21.17	15.8	6.965
	1530	21.32	15.7	7.063
	1545	21.45	15.8	7.163
	1600	21.58	15.9	7.246
	1615	21.69	15.9	7.294
	1630	21.79	16.0	7.356
	1645	21.87	16.1	7.392
	1700	21.94	15.9	7.418
	1715	21.99	16.2	7.431
	1730	22.03	16.2	7.432
	1745	22.06	16.2	7.432
	1800	22.07	16.2	7.398
	1815	22.06	16.0	7.354
	1830	22.04	15.7	7.295
	1845	22.00	15.9	7.199
	1900	21.99	16.1	7.097
	1915	22.02	16.1	6.991
	1930	22.04	16.1	6.880
	1945	22.01	16.0	6.743
	2000	21.96	15.9	6.618
	2015	21.90	15.8	6.488
	2030	21.81	15.7	6.359
	2045	21.74	15.7	6.236
	2100	21.66	15.6	6.102
	2115	21.60	15.5	5.984
	2130	21.54	15.5	5.853
	2145	21.50	15.5	5.753
	2200	21.47	15.4	5.661

(Continued)

(Sheet 3 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		Background		
09/30	2215	21.45	15.4	5.580
	2230	21.44	15.4	5.521
	2245	21.43	15.4	5.478
	2300	21.43	15.4	5.447
	2315	21.42	15.3	5.418
	2330	21.41	15.4	5.422
	2345	21.38	15.4	5.425
		During Dredging and Placement Operations		
10/01	0000	21.37	15.4	5.453
	0015	21.38	15.4	5.493
	0030	21.38	15.4	5.553
	0045	21.37	15.4	5.625
	0100	21.36	15.5	5.698
	0115	21.36	15.5	5.802
	0130	21.35	15.5	5.917
	0145	21.34	15.5	6.039
	0200	21.32	15.6	6.158
	0215	21.29	15.6	6.297
	0230	21.25	15.7	6.418
	0245	21.20	15.7	6.547
	0300	21.15	15.6	6.671
	0315	21.12	15.9	6.789
	0330	21.09	15.9	6.893
	0345	21.05	15.5	6.983
	0400	21.02	16.0	7.068
	0415	21.01	16.0	7.130
	0430	20.99	16.0	7.177
	0445	20.97	16.0	7.206
	0500	20.96	16.1	7.234
	0515	20.94	16.1	7.227
	0530	20.94	16.1	7.212
	0545	20.94	15.9	7.166
	0600	20.90	15.7	7.105
	0615	20.84	15.8	7.034
	0630	20.80	15.8	6.954
	0645	20.77	15.9	6.875

(Continued)

(Sheet 4 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/01	0700	20.74	16.0	6.780
	0715	20.72	16.0	6.660
	0730	20.73	15.9	6.546
	0745	20.75	15.9	6.426
	0800	20.75	15.8	6.302
	0815	20.76	15.7	6.166
	0830	20.79	15.6	6.035
	0845	20.80	15.5	5.908
	0900	20.80	15.5	5.784
	0915	20.80	15.4	5.654
	0930	20.80	15.4	5.529
	0945	20.81	15.3	5.408
	1000	20.83	15.3	5.293
	1015	20.87	15.2	5.181
	1030	20.92	15.2	5.087
	1045	20.98	15.2	5.006
	1100	21.05	15.1	4.940
	1115	21.12	15.1	4.903
	1130	21.16	15.1	4.880
	1145	21.18	15.2	4.880
	1200	21.20	15.1	4.902
	1215	21.21	15.2	4.964
	1230	21.23	15.2	5.041
	1245	21.27	15.3	5.124
	1300	21.35	15.2	5.220
	1315	21.38	15.3	5.341
	1330	21.37	15.3	5.476
	1345	21.36	15.4	5.629
	1400	21.36	15.5	5.779
	1415	21.42	15.6	5.927
	1430	21.61	15.8	6.095
	1445	21.87	15.8	6.260
	1500	22.08	15.9	6.424
	1515	22.23	15.9	6.577
	1530	22.35	15.9	6.723
	1545	22.48	16.0	6.855
	1600	22.62	16.0	6.973

(Continued)

(Sheet 5 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/01	1615	22.75	16.0	7.080
	1630	22.87	16.0	7.168
	1645	22.97	15.9	7.253
	1700	23.04	16.0	7.327
	1715	23.09	16.0	7.385
	1730	23.09	15.9	7.413
	1745	23.05	15.8	7.443
	1800	23.02	15.9	7.455
	1815	23.00	15.8	7.467
	1830	22.95	15.8	7.451
	1845	22.82	15.8	7.418
	1900	22.77	15.9	7.378
	1915	22.86	15.8	7.315
	1930	22.90	15.8	7.237
	1945	22.86	15.8	7.154
	2000	22.84	16.0	7.047
	2015	22.89	15.9	6.944
	2030	22.92	15.9	6.793
	2045	22.91	15.9	6.645
	2100	22.89	15.8	6.504
	2115	22.85	15.8	6.360
	2130	22.80	15.8	6.193
	2145	22.75	15.7	6.041
	2200	22.67	15.6	5.916
	2215	22.59	15.6	5.754
	2230	22.51	15.5	5.607
	2245	22.44	15.5	5.489
	2300	22.37	15.3	5.374
	2315	22.30	15.3	5.277
	2330	22.25	15.3	5.201
	2345	22.21	15.2	5.134
10/02	0000	22.19	13.3	5.088
	0015	22.16	15.2	5.059
	0030	22.14	15.2	5.043
	0045	22.10	15.2	5.049
	0100	22.09	15.2	5.077
	0115	22.10	15.2	5.113

(Continued)

(Sheet 6 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/02	0130	22.10	15.3	5.175
	0145	22.09	15.3	5.254
	0200	22.08	15.3	5.358
	0215	22.09	15.4	5.464
	0230	22.09	15.3	5.583
	0245	22.08	15.4	5.715
	0300	22.08	15.5	5.862
	0315	22.08	15.5	6.007
	0330	22.04	15.4	6.133
	0345	21.99	15.6	6.270
	0400	21.93	15.6	6.402
	0415	21.88	15.5	6.520
	0430	21.85	15.7	6.619
	0445	21.83	15.7	6.717
	0500	21.82	15.6	6.802
	0515	21.82	15.7	6.869
	0530	21.81	15.7	6.926
	0545	21.81	15.6	6.980
	0600	21.80	15.6	7.012
	0615	21.79	15.6	7.043
	0630	21.79	15.6	7.046
	0645	21.78	15.6	7.052
	0700	21.78	15.6	7.026
	0715	21.77	15.5	6.996
	0730	21.71	15.3	6.929
	0745	21.64	15.4	6.881
	0800	21.61	15.4	6.796
	0815	21.61	15.4	6.720
	0830	21.62	15.5	6.612
	0845	21.64	15.5	6.509
	0900	21.62	15.4	6.383
	0915	21.61	15.5	6.252
	0930	21.61	15.7	6.111
	0945	21.61	15.7	5.965
	1000	21.61	15.6	5.835
	1015	21.63	15.6	5.683
	1030	21.64	15.5	5.563

(Continued)

(Sheet 7 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/02	1045	21.65	15.4	5.442
	1100	21.67	15.4	5.323
	1115	21.69	15.3	5.219
	1130	21.70	15.3	5.140
	1145	21.72	15.2	5.065
	1200	21.73	15.2	5.007
	1215	21.75	15.2	4.974
	1230	21.76	15.2	4.954
	1245	21.80	15.2	4.957
	1300	21.83	15.2	4.985
	1315	21.83	15.2	5.040
	1330	21.85	15.3	5.097
	1345	21.88	15.3	5.178
	1400	21.92	15.3	5.276
	1415	21.94	15.3	5.383
	1430	21.94	15.4	5.514
	1445	21.93	15.4	5.650
	1500	21.94	15.5	5.799
	1515	21.98	15.6	5.956
	1530	22.06	15.6	6.113
	1545	22.16	15.7	6.280
	1600	22.29	15.8	6.441
	1615	22.41	15.6	6.582
	1630	22.46	15.8	6.724
	1645	22.49	15.9	6.859
	1700	22.52	16.0	6.970
	1715	22.54	16.0	7.077
	1730	22.55	16.1	7.157
	1745	22.55	16.1	7.234
	1800	22.54	16.2	7.297
	1815	22.54	16.2	7.348
	1830	22.53	16.1	7.398
	1845	22.53	16.1	7.421
	1900	22.51	16.1	7.455
	1915	22.49	16.2	7.456
	1930	22.48	16.4	7.452
	1945	22.47	16.4	7.436

(Continued)

(Sheet 8 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/02	2000	22.45	16.3	7.399
	2015	22.44	15.9	7.351
	2030	22.43	15.9	7.263
	2045	22.41	15.7	7.165
	2100	22.40	15.9	7.065
	2115	22.39	15.8	6.947
	2130	22.40	15.8	6.823
	2145	22.42	15.8	6.691
	2200	22.43	15.6	6.556
	2215	22.43	15.5	6.414
	2230	22.42	15.4	6.271
	2245	22.40	15.4	6.120
	2300	22.38	15.3	5.971
	2315	22.35	15.4	5.829
	2330	22.30	15.4	5.705
	2345	22.25	15.3	5.589
10/03	0000	22.21	15.5	5.494
	0015	22.17	15.4	5.405
	0030	22.13	15.4	5.329
	0045	22.11	15.4	5.275
	0100	22.09	15.3	5.225
	0115	22.07	15.3	5.194
	0130	22.05	15.3	5.197
	0145	22.03	15.3	5.201
	0200	22.03	15.3	5.223
	0215	22.03	15.3	5.276
	0230	22.03	15.3	5.353
	0245	22.03	15.4	5.437
	0300	22.04	15.5	5.552
	0315	22.05	15.4	5.665
	0330	22.08	15.4	5.825
	0345	22.08	15.5	5.972
	0400	22.06	15.5	6.121
	0415	22.05	15.5	6.273
	0430	22.03	15.5	6.413
	0445	22.01	15.7	6.562
	0500	22.00	15.6	6.696

(Continued)

(Sheet 9 of 11)

Table B2 (Continued)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/03	0515	21.98	15.7	6.825
	0530	21.97	15.9	6.982
	0545	21.95	15.8	7.073
	0600	21.93	15.7	7.180
	0615	21.89	16.0	7.317
	0630	21.84	16.0	7.389
	0645	21.81	16.0	7.455
	0700	21.77	16.1	7.569
	0715	21.73	16.1	7.573
	0730	21.69	16.2	7.659
	0745	21.63	16.2	7.668
	0800	21.58	15.9	7.716
	0815	21.54	16.2	7.666
	0830	21.52	16.0	7.697
	0845	21.51	16.2	7.674
	0900	21.51	16.1	7.635
	0915	21.50	15.7	7.613
	0930	21.47	15.9	7.527
	0945	21.45	16.1	7.407
	1000	21.45	16.1	7.310
	1015	21.44	16.0	7.163
	1030	21.44	16.0	7.007
	1045	21.45	15.9	6.849
	1100	21.48	15.9	6.712
	1115	21.52	15.8	6.561
	1130	21.55	15.7	6.397
	1145	21.58	15.6	6.233
	1200	21.60	15.6	6.092
	1215	21.62	15.4	5.952
	1230	21.64	15.3	5.821
	1245	21.65	15.2	5.703
	1300	21.64	15.1	5.588
	1315	21.63	15.0	5.509
	1330	21.62	15.0	5.453
	1345	21.63	14.9	5.406
	1400	21.65	15.0	5.395
	1415	21.70	14.9	5.424

(Continued)

(Sheet 10 of 11)

Table B2 (Concluded)

Date	Sample Time EDT	Temperature deg C	Salinity ppt	Depth ft
		During Dredging and Placement Operations		
10/03	1430	21.71	15.0	5.465
	1445	21.71	15.0	5.540
	1500	21.71	15.1	5.645
	1515	21.73	15.1	5.763
	1530	21.77	15.2	5.902
	1545	21.80	15.0	6.034
	1600	21.86	15.4	6.199
	1615	21.93	15.5	6.361
	1630	22.04	15.6	6.538
	1645	22.18	15.6	6.693
	1700	22.31	15.7	6.843
	1715	22.42	15.8	6.991
	1730	22.49	15.8	7.111
	1745	22.52	15.8	7.227
	1800	22.51	15.2	7.345
	1815	22.49	15.1	7.428
	1830	22.48	15.1	7.523

(Sheet 11 of 11)

Table B3

Suspended Material Concentration, Salinity, and Current Speed and Direction (Team 1)

Date	Station No.	Sample Time EDT*	Depth ft**	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg+
				Background			
09/29	1	1015	2.0	21	11.65	--	--
			6.0	33	11.75	--	--
			9.5	67	11.80	--	--
	2	1027	2.0	19	11.45	--	--
			6.5	33	11.61	--	--
			11.8	63	11.64	--	--
	3	1035	2.0	19	11.19	--	--
			7.0	31	11.46	--	--
			13.4	53	11.55	--	--
	4	1042	2.0	21	11.09	--	--
			7.0	24	11.22	--	--
			13.5	21	11.35	--	--
	5	1057	2.0	12	11.02	--	--
			6.5	27	11.15	--	--
			12.0	43	11.21	--	--
	6	1105	1.0	21	10.93	--	--
			6.5	24	11.05	--	--
			12.2	38	11.10	--	--
	7	1116	1.0	17	10.86	--	--
			6.5	25	11.04	--	--
			12.5	28	11.07	--	--
	8	1124	1.0	16	10.88	--	--
			6.5	--	10.86	--	--
			12.0	26	11.20	--	--
	9	1130	1.0	17	10.87	--	--
			6.0	15	11.01	--	--
			12.0	23	11.17	--	--
	10	1137	1.0	23	10.77	--	--
			5.5	22	11.04	--	--
			13.5	62	11.16	--	--
	11	1145	6.5	13	10.76	--	--
			12.0	28	11.15	--	--
	12	1153	1.0	12	10.37	--	--

(Continued)

*Eastern Daylight Time.
**Surface sample obtained 1 ft below water surface, bottom sample obtained 1 ft above the river bed.
+deg = direction from true north to which the current is flowing (Sheet 1 of 8)

Table B3 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
				Background			
09/29			6.5	13	10.76	--	--
			13.0	20	11.11	--	--
	13	1202	1.0	8	10.38	--	--
			7.0	10	10.55	--	--
			14.5	23	11.04	--	--
	14	1212	1.0	12	11.14	--	--
			5.5	15	11.15	--	--
			12.5	14	11.15	--	--
	15	1219	1.0	--	11.31	--	--
			4.5	15	11.32	--	--
			14.0	16	11.27	--	--
	16	1228	1.0	14	11.48	--	--
			6.5	13	11.47	--	--
			12.5	14	11.29	--	--
	17	1236	1.0	12	11.55	--	--
			7.5	13	11.55	--	--
			14.5	--	11.54	--	--
	18	1242	1.0	13	11.72	--	--
			5.0	18	11.71	--	--
			14.7	14	11.67	--	--
	19	1249	1.0	18	11.73	--	--
			3.0	15	11.67	--	--
			7.5	13	11.74	--	--
	20	1406	1.0	25	12.21	--	--
			3.5	18	12.14	--	--
			17.0	27	12.14	--	--
	21	1419	1.0	16	12.04	--	--
			5.0	19	12.13	--	--
			10.5	18	12.15	--	--
	22	1425	1.0	14	11.75	--	--
			13.0	12	11.78	--	--
			19.5	18	11.74	--	--
	23	1440	1.0	16	12.02	--	--
			5.0	33	12.47	--	--
			7.5	35	12.49	--	--
	24	1451	1.0	25	12.49	--	--
			5.0	23	12.50	--	--

(Continued)

(Sheet 2 of 8)

Table B3 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
				Background			
09/29			8.5	29	12.51	--	--
	25	1456	1.0	24	12.64	--	--
			5.0	--	12.61	--	--
			8.5	31	12.62	--	--
	26	1525	1.0	15	12.78	--	--
			6.0	30	12.94	--	--
			11.0	16	12.97	--	--
	27	1535	1.0	16	12.54	--	--
			6.0	22	12.74	--	--
			15.0	52	13.02	--	--
	28	1545	1.0	17	12.45	--	--
			7.5	28	12.77	--	--
			15.5	20	12.96	--	--
	29	1552	1.0	49	12.37	--	--
			10.0	60	12.96	--	--
			19.0	49	12.99	--	--
	30	1558	1.0	20	12.26	--	--
			10.0	29	12.67	--	--
			19.0	20	12.66	--	--
	31	1608	1.0	18	12.47	--	--
			10.0	22	12.72	--	--
			21.0	37	12.98	--	--
	32	1620	1.0	14	12.66	--	--
			11.0	27	12.88	--	--
			21.0	26	13.08	--	--
	33	1633	1.0	19	12.83	--	--
			7.0	27	12.88	--	--
			20.0	54	13.10	--	--
	34	1640	1.0	14	12.88	--	--
			7.0	10	12.96	--	--
			13.0	23	13.08	--	--
	35	1646	1.0	26	12.77	--	--
			7.5	16	12.92	--	--
			15.5	23	12.96	--	--
09/30	1	1222	1.0	18	10.79	0.2	193
			5.0	14	10.75	0.1	168
			8.5	26	10.91	0.0	195

(Continued)

(Sheet 3 of 8)

Table B3 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
				Background			
09/30	4	1239	1.0	11	11.04	0.4	359
			7.5	12	11.03	0.2	355
			13.0	25	11.24	0.1	240
	6	1249	1.0	9	10.37	0.6	18
			6.0	12	10.76	0.6	28
			11.8	23	11.18	0.5	29
	8	1257	1.0	10	10.13	0.6	21
			6.8	13	10.81	0.7	26
			11.8	31	11.18	0.5	32
	10	1306	1.0	9	9.89	0.7	35
			6.0	13	10.37	0.9	38
			11.0	28	11.04	0.6	45
	13	1316	1.0	8	9.67	0.9	33
			5.5	14	9.89	1.1	38
			12.0	37	10.57	0.9	42
	19	1330	1.0	18	11.49	0.9	5
			2.5	18	11.50	--	--
			5.0	29	11.43	--	--
	32	1336	1.0	21	11.41	0.8	44
			12.0	22	11.43	0.8	39
			22.0	26	11.43	0.7	30
	35	1350	1.0	12	11.28	1.0	34
			7.0	17	11.19	0.7	18
			13.5	30	11.29	0.5	322
	33	1359	1.0	22	11.60	1.0	34
			6.0	28	11.70	0.9	24
			13.0	26	12.47	0.6	8
	31	1410	1.0	36	11.74	1.1	37
			9.0	40	11.72	0.6	27
			17.5	61	11.69	0.8	240
	30	1419	1.0	27	11.45	1.6	21
			12.0	39	11.47	0.8	3
			22.0	84	11.80	0.5	227
	28	1431	1.0	16	11.59	1.0	354
			7.0	15	11.59	0.6	353
			14.5	25	11.59	0.3	200
	27	1441	1.0	26	11.93	1.0	357

(Continued)

(Sheet 4 of 8)

Table B3 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
				Background			
09/30			7.0	30	11.94	0.7	41
			14.0	54	11.98	0.5	92
	23	1458	1.0	35	12.37	1.2	3
			4.0	35	12.40	0.5	359
			8.0	47	12.41	0.3	307
	21	1504	1.0	30	12.17	1.0	16
			9.0	39	12.51	1.0	30
			17.0	41	12.50	0.9	40
	17	1519	1.0	35	12.64	0.8	16
			8.0	34	12.64	0.7	24
			14.0	37	12.65	0.9	65
	14	1528	1.0	21	12.72	1.0	2
			6.0	24	12.73	0.5	7
			12.0	24	12.75	0.8	350
	1	1620	1.0	30	12.46	0.6	357
			6.5	53	12.40	0.6	355
			12.0	57	12.39	0.5	359
	4	1630	1.0	29	11.42	1.1	15
			7.0	29	12.48	1.2	17
			15.0	85	12.46	1.3	18
	6	1645	1.0	21	12.50	1.4	30
			6.5	33	13.20	1.2	23
			13.0	115	13.59	1.0	21
	8	1650	1.0	19	12.73	1.4	31
			6.5	42	13.37	1.2	30
			13.7	86	13.74	0.9	29
	10	1656	1.0	17	13.01	1.3	41
			6.0	39	13.40	1.1	38
			13.0	98	13.60	1.0	37
	13	1704	1.0	22	13.08	1.0	44
			7.5	27	13.30	1.0	37
			14.5	74	13.55	0.9	31
10/01	32	1030	1.0	21	12.07	1.2	213
			11.0	30	13.05	0.9	226
			21.0	15,702	13.02	0.3	196
			21.0	4,168	13.21	0.3	196
	19	1049	1.0	6	11.53	0.8	229

(Continued)

(Sheet 5 of 8)

Table B3 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
			During Dredged Material Placement				
10/01			3.0	15	11.74	--	--
			5.0	16	12.23	--	--
	9	1057	1.0	20	11.26	1.2	223
			5.5	30	12.00	1.0	224
			11.0	47	12.30	0.8	223
	32.5	1101	1.0	16	10.87	1.1	223
			7.0	24	12.73	0.6	231
			14.0	29	13.07	0.6	12
	18	1105	1.0	11	10.78	1.2	227
			5.5	17	11.55	0.9	236
			12.0	97	12.31	0.5	236
	7	1154	1.0	26	11.15	0.7	219
			6.0	46	12.67	0.5	231
			12.5	47	12.75	0.8	229
	31.5	1159	1.0	22	11.11	1.0	229
			9.0	24	11.58	0.6	219
			19.0	273	12.25	0.5	209
	20	1203	2.0	16	11.10	0.6	241
			4.5	17	11.09	--	--
	21	1214	1.0	14	10.73	--	--
			12.0	29	11.32	--	--
			23.0	11,071	12.89	--	--
	31	1218	1.0	17	10.71	--	--
			8.0	40	11.80	--	--
			17.0	35	12.22	--	--
	21.5	1231	2.0	39	10.86	--	--
			4.0	53	10.86	--	--
	91	1250	1.0	13	10.70	0.8	238
			9.5	29	11.89	0.5	205
			18.5	33	12.05	0.4	185
	30.5	1254	1.0	10	10.65	0.2	264
			9.5	20	11.34	0.2	222
			20.0	38	12.27	0.3	236
	22	1259	1.0	15	10.80	0.1	221
			4.5	15	10.82	0.1	105
			10.0	20	11.27	0.2	96
	72	1438	1.0	9	11.82	0.8	346

(Continued)

(Sheet 6 of 8)

Table B3 (Continued)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
During Dredged Material Placement (Continued)							
10/01			7.0	17	12.39	0.9	353
			14.0	21	12.35	0.6	1
	22	1444	3.0	12	12.03	0.7	336
			5.0	16	12.23	--	--
	21	1449	1.0	18	11.90	--	--
			13.0	23	12.12	--	--
			26.0	4,846	13.47	--	--
	19	1456	1.0	13	12.06	0.5	4
			3.0	13	12.07	--	--
			6.0	16	12.10	--	--
	17	1504	1.0	18	11.90	0.8	2
			9.0	19	12.16	0.9	24
			19.0	19	12.20	0.7	43
	8	1804	1.0	38	12.81	1.0	21
			7.0	32	13.38	0.8	16
			14.0	46	13.71	0.7	14
	32	1814	1.0	38	13.31	0.7	37
			8.0	57	13.59	0.6	27
			15.0	108	13.74	0.3	22
	32.5	1819	1.0	18	13.69	0.6	33
			8.0	21	13.74	0.5	22
			17.0	30	14.01	0.4	13
	9	1825	1.0	16	13.09	0.7	40
			9.0	21	13.44	0.6	35
			14.0	173	13.78	0.5	29
	18	1831	1.0	24	14.18	0.5	22
			3.5	21	14.26	0.4	23
			8.0	26	14.18	--	--
	19	1836	1.0	38	14.24	0.5	0
			3.0	28	14.24	--	--
			6.0	40	14.26	--	--
10/02	6	1431	1.0	13	10.91	0.4	262
			6.0	16	11.24	0.3	260
			13.0	15	11.66	0.2	254
	31	1438	1.0	16	11.11	0.3	274
			9.5	10	11.13	0.3	265
			18.0	45	12.09	0.1	266

(Continued)

(Sheet 7 of 8)

Table B3 (Concluded)

Date	Station No.	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt	Current Speed ft/sec	Current Direction deg
			During Dredged Material Placement (Concluded)				
10/02	21	1442	1.0	13	11.18	0.4	295
			12.0	30	12.41	0.2	340
			24.0	--	-.-	0.3	46
	19	1449	1.0	30	11.19	0.3	301
			5.0	30	11.18	--	--
	32	1456	1.0	19	11.01	0.4	279
			13.0	53	11.31	0.4	273
	8	1501	1.0	9	10.95	0.3	295
			6.0	22	11.19	0.3	327
			11.0	12	11.44	0.2	23
	10	1511	1.0	14	10.91	0.3	324
			6.0	11	11.07	0.3	323
			12.0	13	11.31	0.3	335
	33	1519	1.0	9	11.22	0.4	350
			7.0	14	11.26	0.5	3
			14.0	58	11.80	0.5	9
	17	1526	1.0	15	11.59	0.6	11
			6.0	15	11.60	0.6	13
			12.0	13	11.61	0.5	11

(Sheet 8 of 8)

Table B4

Suspended Material Concentration, Salinity, and Current Speed and Direction (Team 2)

Date Month/Day	Sample Time EDT*	Depth ft**	Material Concentration mg/ℓ	Salinity ppt Salinometer	Salinity ppt Water Samples	Current Speed ft/sec	Current Direction deg+
			Station 1, Background				
09/30	1314	5.6	22	11.2	11.2	0.6	340
	1316	3.8	21	11.2	11.3	0.8	355
	1318	2.0	19	11.2	11.3	0.9	5
	1350	2.0	26	11.8	11.8	0.9	20
	1353	5.3	26	11.9	11.8	0.8	15
	1354	3.6	25	11.8	11.8	0.9	20
	1500	5.6	47	12.6	12.6	1.0	15
	1501	3.9	47	12.5	11.6	1.2	20
	1502	2.0	43	12.5	12.6	1.2	25
	1600	5.8	102	13.0	13.0	0.9	10
	1602	3.9	99	12.9	13.1	1.0	15
	1604	2.0	85	12.9	13.1	1.1	10
	1645	5.8	46	13.7	14.0	0.9	10
	1647	3.9	54	13.7	14.2	0.9	20
	1649	2.0	44	13.4	14.2	1.0	15
			Station 1, During Dredging				
10/01	0903	5.5	17	12.3	12.6	0.4	200
	0905	3.8	15	12.0	12.4	0.7	215
	0907	2.0	11	11.9	12.1	1.1	210
	1012	4.5	12	11.3	11.7	0.9	255
	1014	2.0	12	11.1	11.6	1.3	250
	1100	4.6	17	11.4	11.8	0.8	242
	1102	2.0	16	11.4	11.7	1.0	240
	1201	5.0	17	11.1	11.3	0.6	270
	1203	3.5	16	10.9	11.2	0.6	15
	1205	2.0	15	10.8	11.2	0.7	255
	1300	4.2	11	10.4	10.6	0.4	285
	1302	2.0	13	10.3	10.6	0.4	285
	1406	5.0	14	11.2	11.0	0.3	305

(Continued)

*Eastern Daylight Time.
**Surface sample obtained 2 ft below water surface, bottom sample obtained 2 ft above the river bed.
+deg = direction from true north to which the current is flowing. (Sheet 1 of 7)

Table B4 (Continued)

Date Month/Day	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt Salinometer	Salinity ppt Water Samples	Current Speed ft/sec	Current Direction deg
10/01	1408	3.5	14	10.9	11.0	0.3	20
	1410	2.0	11	10.8	11.1	0.4	10
	1503	5.2	12	12.1	12.5	0.7	10
	1505	3.6	11	11.9	12.5	1.0	260
	1507	2.0	11	11.9	12.5	1.2	10
	1600	5.6	25	13.1	13.4	0.8	20
	1602	3.8	22	13.1	13.4	1.1	5
	1604	2.0	21	13.0	13.4	1.2	20
	1645	6.0	21	13.2	13.2	0.9	20
	1647	4.0	21	12.7	13.2	1.1	10
	1649	2.0	18	12.7	13.2	0.9	20
10/02	0915	6.4	21	13.3	13.6	0.1	181
	0917	4.2	17	13.0	13.6	0.3	190
	0919	2.0	12	12.0	12.4	0.5	185
	1001	5.7	16	12.6	13.3	0.3	235
	1003	3.8	16	12.4	12.9	0.6	220
	1005	2.0	13	11.5	12.4	0.9	212
	1110	5.2	15	11.9	12.2	0.9	225
	1112	3.6	14	11.9	12.2	0.9	250
	1114	2.0	14	11.6	12.2	1.1	250
	1202	4.8	13	12.1	12.5	1.0	255
	1204	3.4	13	12.1	12.5	1.1	250
	1206	2.0	14	12.0	12.5	1.0	255
	1300	4.7	16	11.3	11.7	0.6	260
	1302	3.4	15	11.2	11.7	0.7	265
	1304	2.0	14	11.3	11.7	0.8	260
	1400	4.9	13	10.9	11.0	0.3	290
	1402	3.5	13	10.7	11.1	0.4	285
	1404	2.0	6	10.5	11.1	0.4	285
	1459	5.3	9	11.4	11.3	0.3	10
	1501	3.7	8	11.0	11.3	0.3	5
	1503	2.0	9	10.8	11.3	0.5	20
	1602	5.6	15	12.9	12.4	0.8	20
	1604	3.8	15	12.3	12.4	0.6	30
	1606	2.0	14	12.1	12.4	0.7	20
			Station 2, Background				
09/30	1320	6.9	23	11.8	11.7	0.5	2
	1322	3.9	21	11.8	11.7	0.8	10
	1324	2.0	17	11.7	11.7	0.9	10

(Continued)

(Sheet 2 of 7)

Table B4 (Continued)

Date Month/Day	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt Salinometer	Salinity ppt Water Samples	Current Speed ft/sec	Current Direction deg
09/30	1400	7.7	29	12.0	11.9	0.7	35
	1401	4.9	28	11.9	12.0	0.7	30
	1402	2.0	30	11.8	12.0	0.8	30
	1510	7.7	49	12.7	12.7	1.0	20
	1512	4.9	32	12.7	12.6	1.1	20
	1514	2.0	40	12.6	12.7	1.2	25
	1608	7.2	62	13.5	13.7	1.0	20
	1610	4.6	36	13.4	13.7	1.1	20
	1612	2.0	33	13.2	13.8	1.2	25
	1655	7.8	43	13.3	14.4	1.0	52
	1657	4.9	40	13.3	14.4	1.1	45
	1659	2.0	41	13.2	14.4	1.0	50
			Station 2, During Dredging				
10/01	0920	5.8	15	11.5	11.9	0.5	75
	0922	3.9	13	11.4	11.8	0.8	270
	0924	2.0	12	11.4	11.8	0.9	250
	1021	5.2	12	11.7	12.2	0.6	228
	1022	3.6	12	11.5	12.2	1.0	222
	1022	2.0	15	11.5	12.2	1.1	228
	1107	5.3	18	11.4	11.7	1.0	250
	1109	3.7	16	11.2	11.7	1.0	235
	1111	2.0	16	11.2	11.7	1.0	232
	1212	5.8	14	10.9	11.1	0.4	270
	1214	3.9	15	10.7	11.1	0.6	255
	1216	2.0	14	10.5	11.0	0.7	250
	1308	6.1	13	10.7	10.9	0.5	310
	1310	4.1	12	10.6	10.0	0.3	290
	1312	2.0	11	10.5	10.6	0.3	290
	1412	6.7	12	11.1	11.3	0.5	85
	1414	4.4	10	11.1	11.3	0.4	20
	1416	2.0	10	10.9	11.4	0.4	20
	1513	7.2	14	12.3	12.9	0.5	25
	1515	4.6	14	12.4	12.9	0.8	20
	1517	2.0	15	12.5	12.9	1.1	20
	1608	7.5	23	13.3	13.5	0.5	45
	1610	4.8	24	13.2	13.5	0.7	25
	1612	2.0	24	13.2	13.5	1.2	30
	1652	7.7	26	13.3	13.4	0.6	30
	1654	5.8	22	13.1	13.4	0.8	35

(Continued)

(Sheet 3 of 7)

Table B4 (Continued)

Date Month/Day	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt Salinometer	Salinity ppt Water Samples	Current Speed ft/sec	Current Direction deg
10/01	1656	2.0	19	13.1	13.5	0.9	25
10/02	0928	5.9	20	13.2	13.6	0.3	185
	0930	4.0	14	13.1	13.5	0.4	192
	0932	2.0	13	12.1	13.2	0.7	190
	1011	5.5	12	12.9	13.1	0.5	200
	1013	3.8	12	12.3	12.7	0.8	210
	1015	2.0	12	12.3	12.5	0.9	210
	1118	5.2	20	11.9	12.1	0.9	230
	1120	3.6	20	11.9	12.1	1.0	225
	1122	2.0	15	11.8	12.1	1.0	230
	1209	5.6	15	11.8	12.3	0.8	250
	1211	3.8	15	11.8	12.3	1.0	235
	1213	2.0	16	11.8	12.3	0.9	238
	1307	6.1	14	11.4	11.6	0.4	280
	1309	4.1	14	11.4	11.6	0.8	170
	1317	2.0	14	11.2	11.6	0.8	120
	1410	6.3	10	11.0	11.3	0.1	250
	1412	4.2	9	11.0	11.3	0.3	290
	1414	2.0	9	10.9	11.3	0.2	290
	1508	7.0	11	11.3	11.6	0.1	290
	1510	4.5	10	11.3	11.6	0.3	45
	1512	2.0	11	11.3	11.7	0.4	30
	1612	7.6	14	12.4	12.9	0.7	30
	1614	4.8	14	12.4	12.9	0.9	10
	1615	2.0	16	12.4	12.9	0.8	30
			Station 3, Background				
09/30	1335	4.6	26	11.6	11.4	1.0	15
	1337	2.0	24	11.5	11.6	1.3	10
	1412	5.1	28	12.1	12.1	1.0	30
	1413	3.6	30	12.1	12.2	1.2	32
	1414	2.0	31	12.1	12.2	1.3	32
	1523	5.0	43	12.7	12.7	1.2	35
	1525	3.5	36	12.7	12.8	1.4	30
	1527	2.0	35	12.7	12.8	1.6	20
	1616	5.3	42	13.4	13.7	1.2	35
	1618	3.7	48	13.3	13.2	1.3	35
	1620	2.0	46	13.1	13.2	1.3	30
	1703	5.0	45	13.4	14.3	1.0	20
	1706	3.5	44	13.4	14.3	1.1	30

(Continued)

(Sheet 4 of 7)

Table B4 (Continued)

Date Month/Day	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt		Current Speed ft/sec	Current Direction deg
				Salinometer	Water Samples		
09/30	1708	2.0	46	13.4	14.3	1.2	40
			Station 3, During Dredging				
10/01	0931	2.6	13	12.0	12.5	2.0	210
	1031	2.3	17	12.1	12.4	1.9	215
	1116	2.3	18	11.3	11.7	1.6	220
	1222	2.8	13	10.4	10.8	0.9	240
	1318	3.8	11	10.4	10.7	0.3	320
	1320	2.0	11	10.2	10.6	0.3	305
	1424	4.9	14	11.3	11.4	0.8	30
	1426	3.5	11	11.1	11.4	0.8	30
	1428	2.0	10	11.0	11.4	0.9	32
	1524	5.3	15	12.7	13.0	1.0	20
	1526	3.6	15	12.7	13.1	1.5	20
	1528	2.0	16	12.5	13.1	1.7	15
	1621	5.6	24	13.1	13.3	1.2	30
	1623	3.8	27	13.1	13.5	1.2	30
	1625	2.0	26	13.0	13.5	1.5	30
	1702	5.6	18	13.3	13.4	1.2	20
	1704	3.8	23	13.2	13.4	1.4	25
	1706	2.0	18	13.0	13.4	1.4	30
10/02	0937	3.5	13	12.8	13.6	0.8	202
	1022	3.0	12	12.2	12.8	1.5	205
	1128	2.7	12	12.0	12.5	2.0	220
	1219	2.5	15	11.8	12.3	2.0	225
	1316	2.4	14	11.0	11.4	1.2	240
	1418	3.4	8	11.0	11.2	0.3	320
	1517	4.7	10	11.2	11.5	0.6	15
	1521	2.0	8	11.2	11.5	0.8	30
	1620	4.9	24	12.4	12.6	1.1	20
	1622	2.0	21	12.3	12.7	1.4	20
			Station 4, Background				
09/30	1340	14.3	38	11.5	11.5	1.0	70
	1342	8.2	26	11.4	11.4	1.1	60
	1345	2.0	25	11.4	11.4	0.9	60
	1420	14.4	29	12.0	11.9	1.0	45
	1421	8.2	32	12.0	11.9	1.0	55
	1422	2.0	31	12.0	11.9	1.2	55

(Continued)

(Sheet 5 of 7)

Table B4 (Continued)

Date Month/Day	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt Salinometer	Salinity ppt Water Samples	Current Speed ft/sec	Current Direction deg
09/30	1533	14.8	45	12.6	12.7	1.2	50
	1535	8.4	44	12.6	12.7	1.3	65
	1537	2.0	46	12.6	12.7	1.3	55
	1626	15.4	57	13.1	13.0	1.0	50
	1628	8.7	51	13.0	13.0	1.2	60
	1630	2.0	52	12.9	13.0	1.1	45
	1712	15.3	44	13.2	14.2	1.2	65
	1714	8.7	35	12.8	14.1	1.2	55
	1716	2.0	29	12.6	13.8	1.1	55
			Station 4, During Dredging				
10/01	0942	13.6	24	13.1	13.6	0.6	275
	0943	7.8	17	12.6	13.3	1.8	242
	0945	2.0	9	10.7	11.3	1.8	242
	1041	13.7	34	12.8	13.2	0.5	270
	1043	7.8	19	12.6	12.9	0.9	265
	1045	2.0	16	11.4	11.9	1.6	240
	1129	13.5	30	12.2	12.7	0.5	270
	1131	7.8	22	12.0	12.3	1.0	260
	1132	2.0	22	11.0	11.3	1.6	230
	1234	14.0	18	11.2	11.6	0.5	285
	1236	8.0	19	11.1	11.6	0.6	285
	1238	2.0	17	10.0	10.4	1.2	250
	1326	14.1	14	10.7	11.1	0.1	290
	1328	8.0	11	10.3	10.7	0.2	330
	1330	2.0	9	10.1	10.3	0.5	300
	1435	14.7	48	12.1	12.4	0.6	80
	1437	8.3	15	11.2	11.4	0.6	70
	1439	2.0	11	10.9	11.3	0.5	55
	1533	15.0	20	12.6	12.9	0.7	20
	1535	8.5	20	12.5	12.9	0.7	60
	1537	2.0	24	12.4	12.9	0.6	50
	1628	14.9	68	13.2	13.5	0.7	70
	1630	8.5	39	13.1	13.5	0.8	55
	1632	2.0	27	13.1	13.5	0.8	50
	1710	15.0	86	12.9	13.3	0.6	40
	1712	8.5	33	12.5	13.3	0.8	30
	1714	2.0	56	12.8	13.2	0.7	60
10/02	0943	14.5	20	13.2	13.8	0.2	265
	0945	8.3	21	13.0	13.5	0.3	245

(Continued)

(Sheet 6 of 7)

Table B4 (Concluded)

Date Month/Day	Sample Time EDT	Depth ft	Material Concentration mg/ℓ	Salinity ppt		Current Speed ft/sec	Current Direction deg
				Salinometer	Water Samples		
10/02	0947	2.0	22	11.5	12.0	0.8	215
	1033	14.4	26	13.4	13.6	0.2	300
	1035	8.2	14	12.2	13.6	0.5	270
	1037	2.0	12	11.8	12.2	1.6	240
	1133	14.0	20	13.1	13.3	0.7	295
	1135	8.0	16	12.7	13.1	1.0	270
	1137	2.0	11	12.0	12.4	1.8	242
	1224	14.0	25	12.8	13.1	0.8	305
	1225	8.0	19	12.6	13.0	1.0	280
	1226	2.0	18	11.7	12.0	1.5	240
	1321	14.0	17	12.0	12.1	0.3	290
	1323	8.0	14	11.5	11.9	0.8	275
	1325	2.0	17	10.9	11.2	1.3	245
	1423	14.2	15	10.9	11.4	0.2	310
	1424	8.1	9	11.0	11.2	0.5	310
	1425	2.0	7	10.6	10.9	0.6	290
	1523	14.6	55	12.1	12.6	0.9	70
	1524	8.3	6	11.1	11.4	0.5	50
	1526	2.0	5	11.1	11.3	0.3	40
	1631	14.7	108	12.2	12.6	0.8	70
	1633	8.4	31	12.1	12.4	0.8	55
	1635	2.0	58	12.1	12.6	0.5	45

(Sheet 7 of 7)

Table B5

Automatic Water Sampler Suspended Material Concentration and Salinity (Stations 2.5 and 4.5)

Sample Number	Sample Time EDT*	Concentration mg/ℓ	Salinity ppt
	Station 2.5 (30 September through 2 October)		
1	1218-1657**	26	11.6
2	1830-2309	29	14.6
3	0042-0521	14	12.0
4	0654-1133	12	13.3
5	1306-1745	18	11.8
6	1918-0057	27	13.8
7	0230-0709	19	12.6
8	0842-1321	16	13.3
9	1454-1727	12	11.6
	Station 4.5 (2 October)		
1	1130	58	13.3
2	1200	87	13.5
3	1230	77	13.3
4	1300	60	13.2
5	1330	44	12.9
6	1400	46	12.5
7	1430	34	12.2
8	1500	34	12.2
9	1530	52	12.5
10	1600	43	12.7
11	1630	69	12.7
12	1700	160	12.8

*Eastern Daylight Time.

**One composite sample contained four 200-mℓ samples taken per 6-hr time period.

APPENDIX C: BOTTOM SEDIMENT SAMPLE GRAIN SIZE[1]

Results from grain size analyses are contained in the plates that follow. Analytic procedures are described in the main text. Station number, sampling date, and percent moisture are given in the bottom-right box on each plate. Station locations are given on Figure 17 of the main text. Percent moisture is 100 times the sample water weight divided by the sediment weight, as described in the main text. Cumulative and differential frequency distributions of grain size are given on each plot. Summary statistics, computed from distributions, including the median, mode, mean, sorting (standard deviation), skewness, size of the coarsest 5 percent, and percent of size greater than 0.074 mm are given on each plate.

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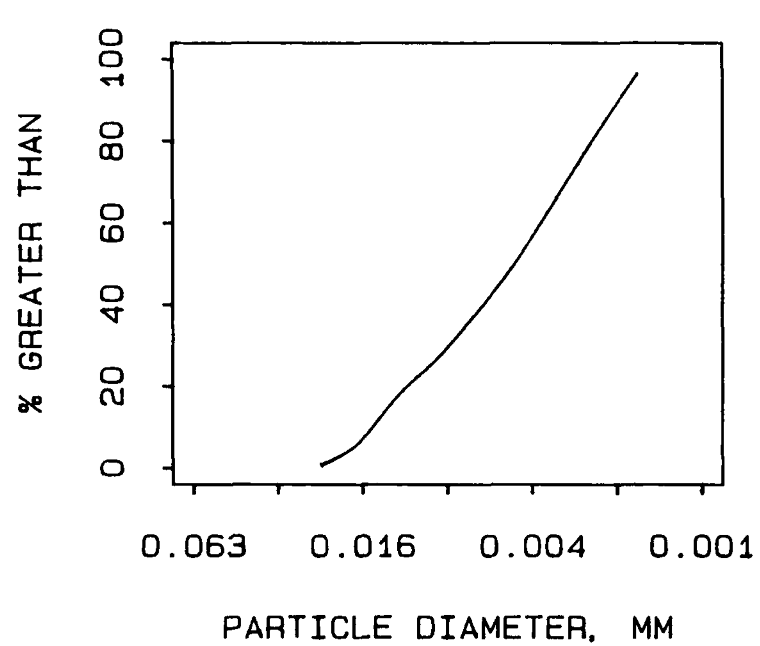
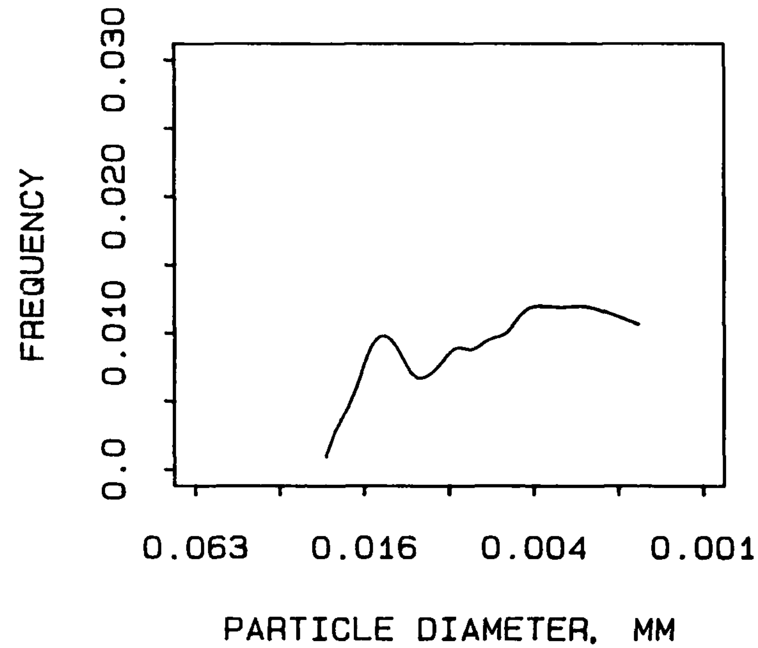
[1]Written by Mr. Allen M. Teeter.





MEDIAN: 7.79 PHI, 0.0045 MM

MODE: 0.0026 MM

MEAN: 7.64 PHI, 0.005 MM

SORTING: 1.21 PHI

SKEWNESS: -0.141

COARSEST 5%: 5.91 PHI, 0.0166 MM

% GREATER THAN 0.074 MM: 0.9

PROJECT: Tylers Beach, VA

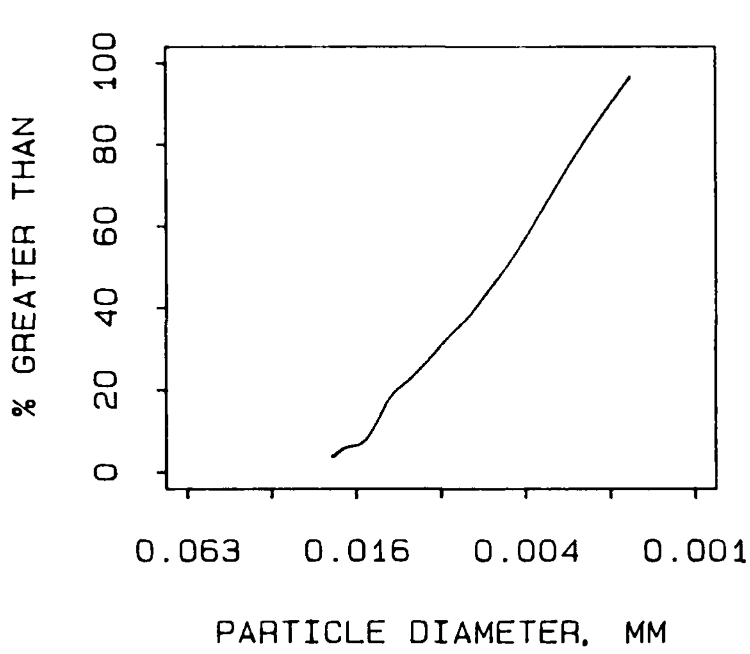
STATION: 1

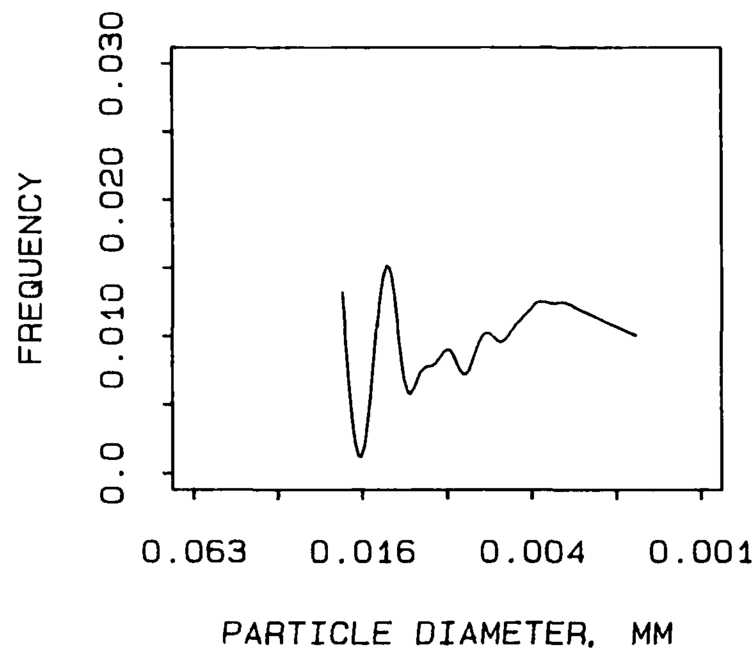
SAMPLE TYPE: Grab

DEPTH: 10.0

DATE: 9/30/91

PERCENT MOISTURE: 199





MEDIAN: 7.77 PHI, 0.0046 MM

MODE: 0.0128 MM

MEAN: 7.62 PHI, 0.0051 MM

SORTING: 1.2 PHI

SKEWNESS: -0.145

COARSEST 5%: 5.78 PHI, 0.0182 MM

% GREATER THAN 0.074 MM: 0.9

PROJECT: Tylers Beach, VA

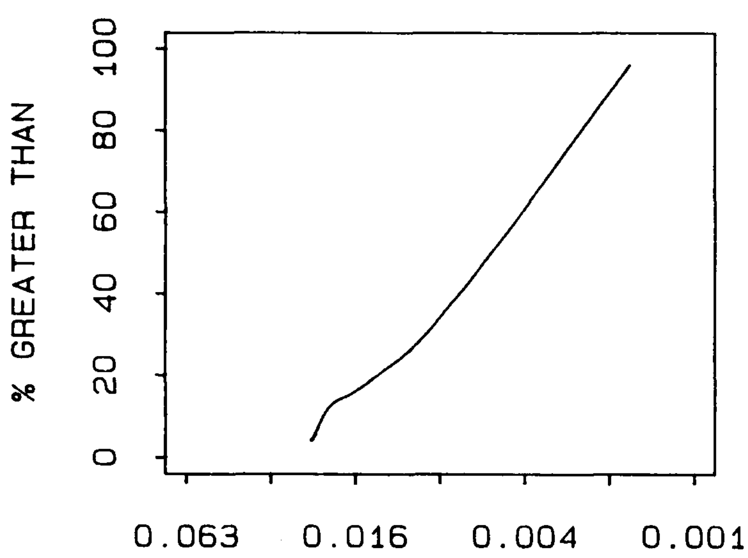
STATION: 4

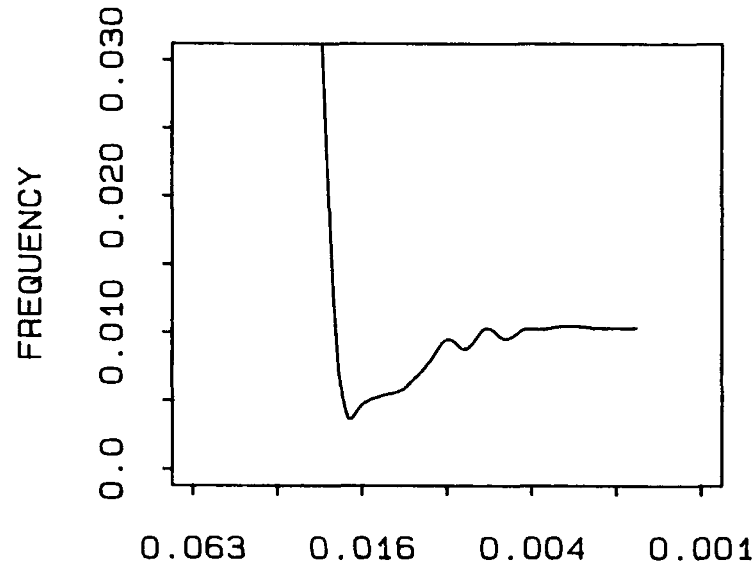
SAMPLE TYPE: Grab

DEPTH: 13.0 ft

DATE: 9/30/91

PERCENT MOISTURE: 228





MEDIAN: 7.59 PHI, 0.0052 MM

MODE: 0.0219 MM

MEAN: 7.45 PHI, 0.0057 MM

SORTING: 1.36 PHI

SKEWNESS: -0.101

COARSEST 5%: 5.51 PHI, 0.022 MM

% GREATER THAN 0.074 MM: 2.9

PROJECT: Tylers Beach, VA

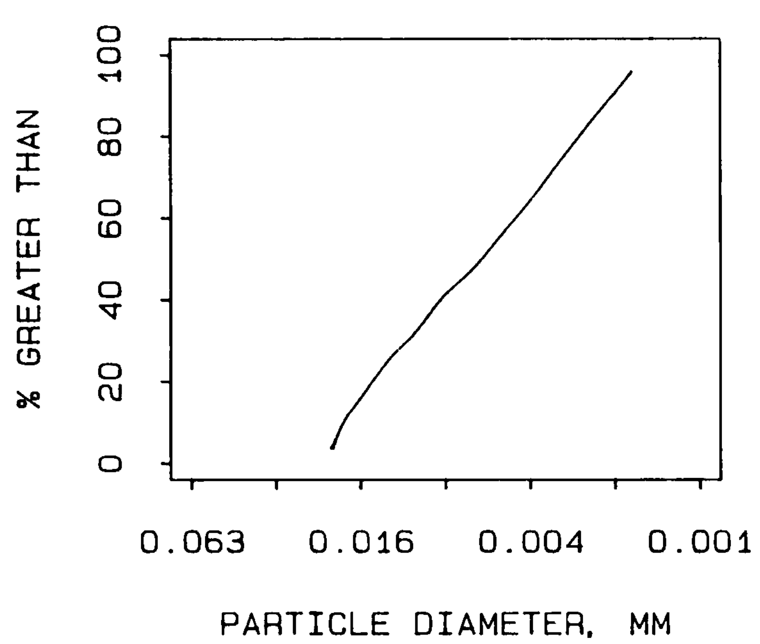
STATION: 6

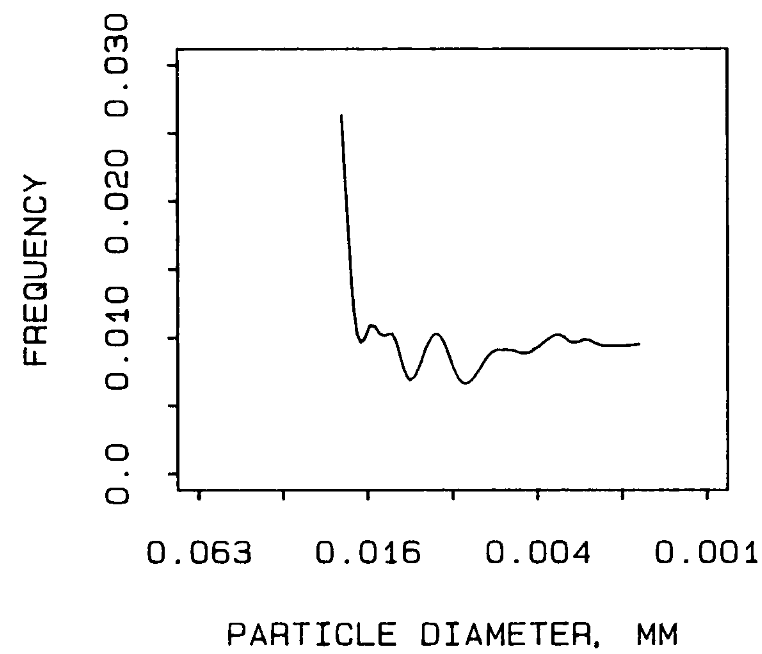
SAMPLE TYPE: Grab

DEPTH: 11.8 ft

DATE: 9/30/91

PERCENT MOISTURE: 215





MEDIAN: 7.42 PHI, 0.0058 MM

MODE: 0.0189 MM

MEAN: 7.38 PHI, 0.006 MM

SORTING: 1.39 PHI

SKEWNESS: -0.043

COARSEST 5%: 5.69 PHI, 0.0194 MM

% GREATER THAN 0.074 MM: 2.4

PROJECT: Tylers Beach, VA

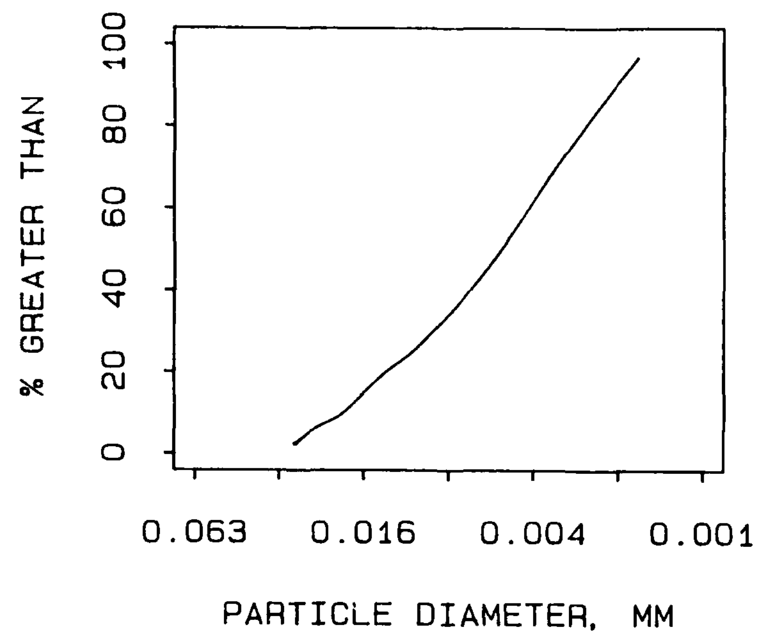
STATION: 8

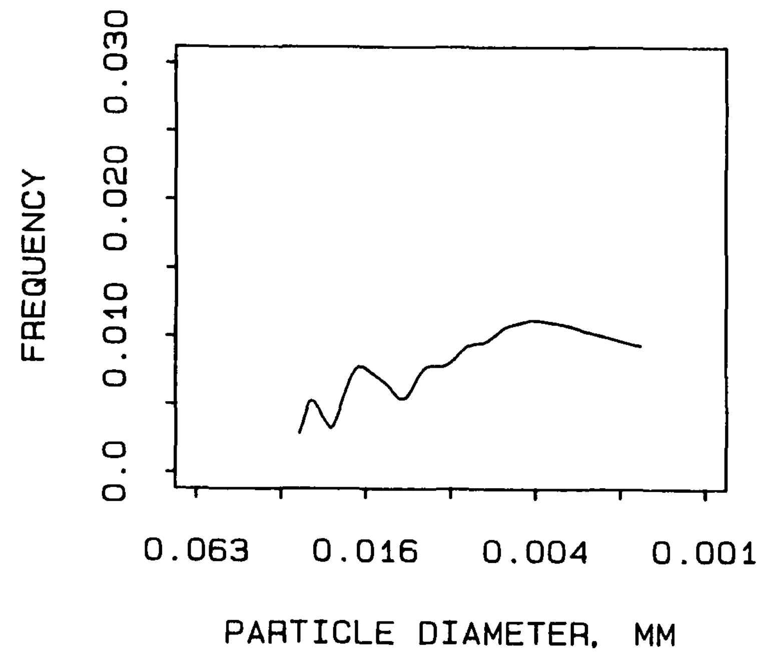
SAMPLE TYPE: Grab

DEPTH: 11.8 ft

DATE: 9/30/91

PERCENT MOISTURE: 185





MEDIAN: 7.61 PHI, 0.0051 MM

MODE: 0.0248 MM

MEAN: 7.44 PHI, 0.0058 MM

SORTING: 1.3 PHI

SKEWNESS: -0.138

COARSEST 5%: 5.32 PHI, 0.0251 MM

% GREATER THAN 0.074 MM: 6.0

PROJECT: Tylers Beach, VA

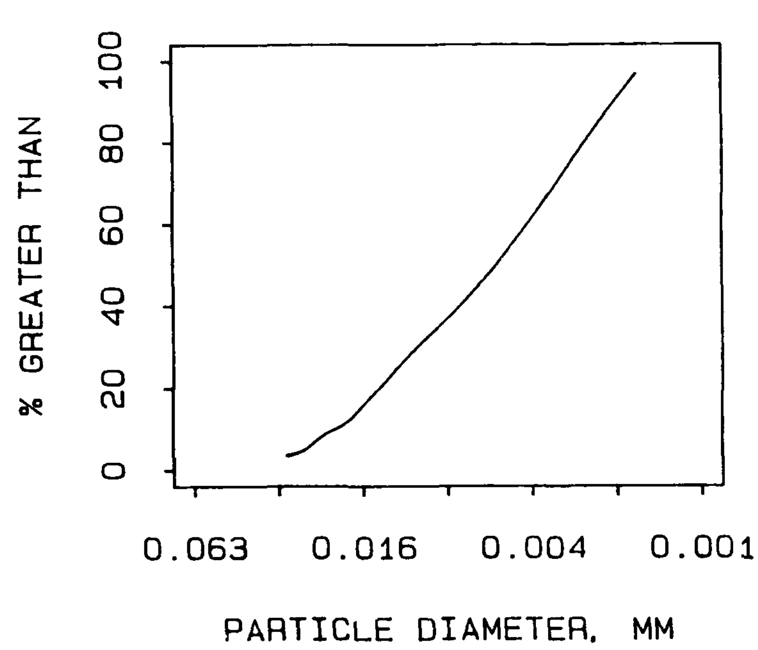
STATION: 10

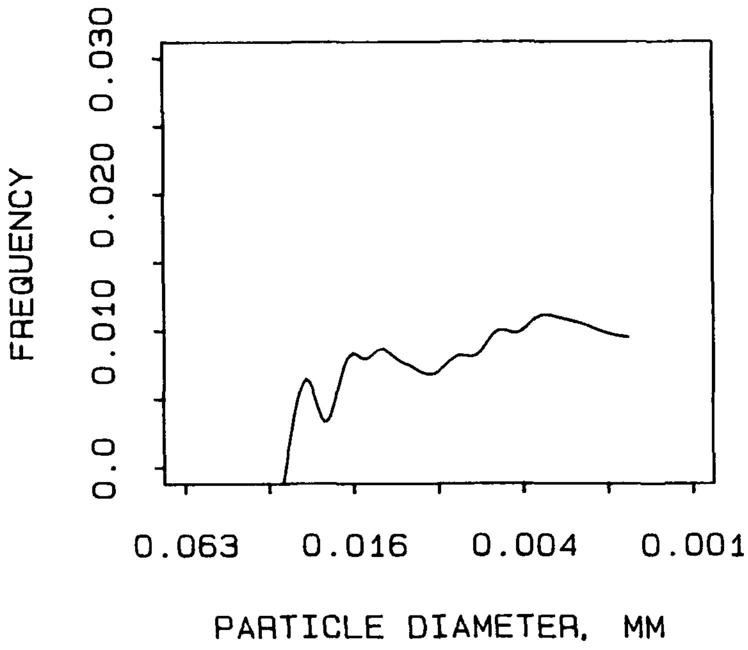
SAMPLE TYPE: Grab

DEPTH: 11.0

DATE: 9/30/91

PERCENT MOISTURE: 164





MEDIAN: 7.58 PHI, 0.0052 MM

MODE: 0.0034 MM

MEAN: 7.4 PHI, 0.0059 MM

SORTING: 1.39 PHI

SKEWNESS: -0.145

COARSEST 5%: 5.35 PHI, 0.0244 MM

% GREATER THAN 0.074 MM: 3.7

PROJECT: Tylers Beach, VA

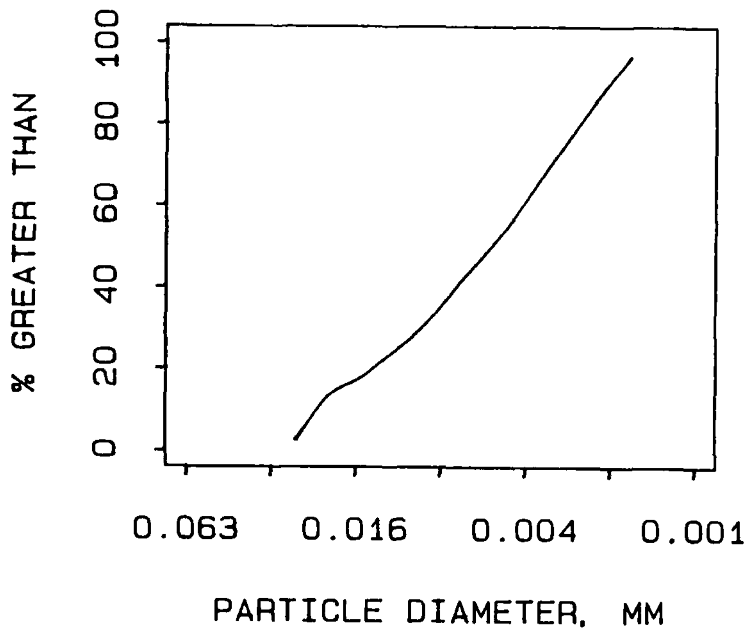
STATION: 13

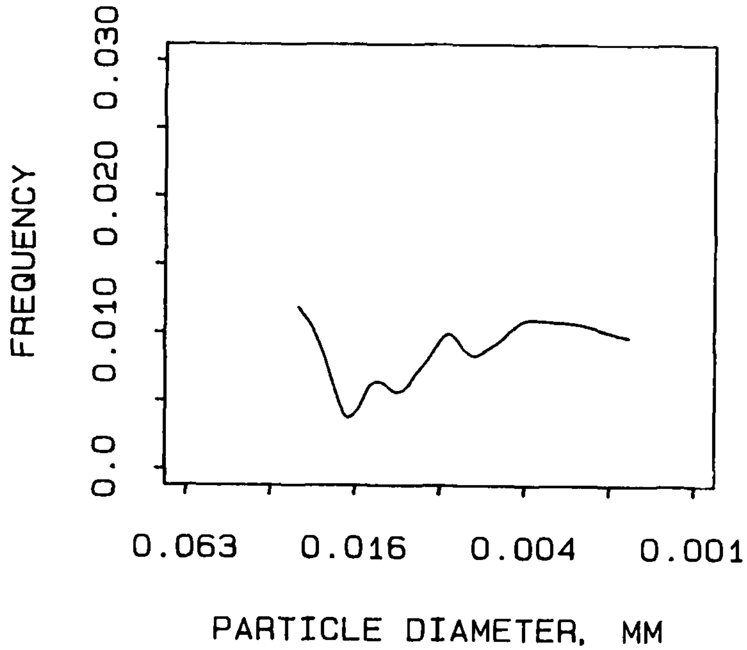
SAMPLE TYPE: Grab

DEPTH: 12.0

DATE: 9/30/91

PERCENT MOISTURE: 186





MEDIAN: 7.6 PHI, 0.0052 MM

MODE: 0.0248 MM

MEAN: 7.39 PHI, 0.006 MM

SORTING: 1.39 PHI

SKEWNESS: -0.15

COARSEST 5%: 5.34 PHI, 0.0247 MM

% GREATER THAN 0.074 MM: 16.4

PROJECT: Tylers Beach, VA

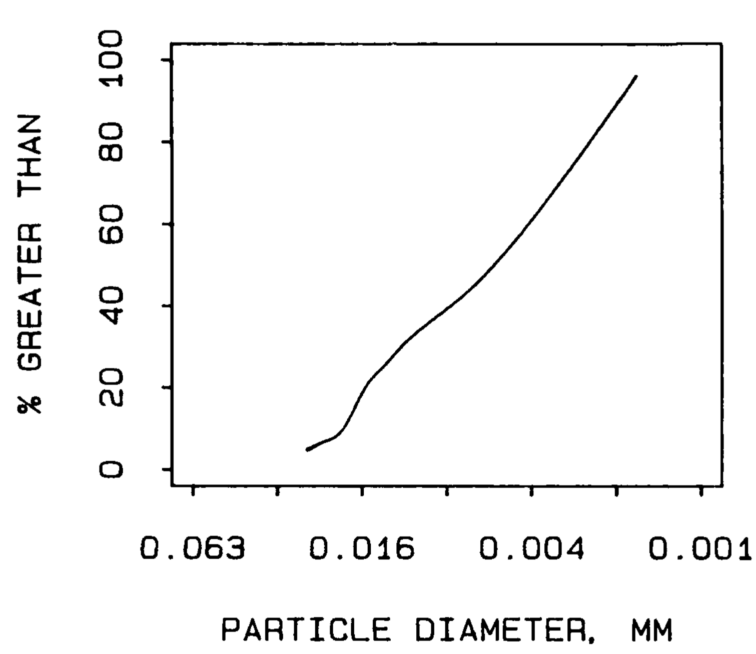
STATION: 17

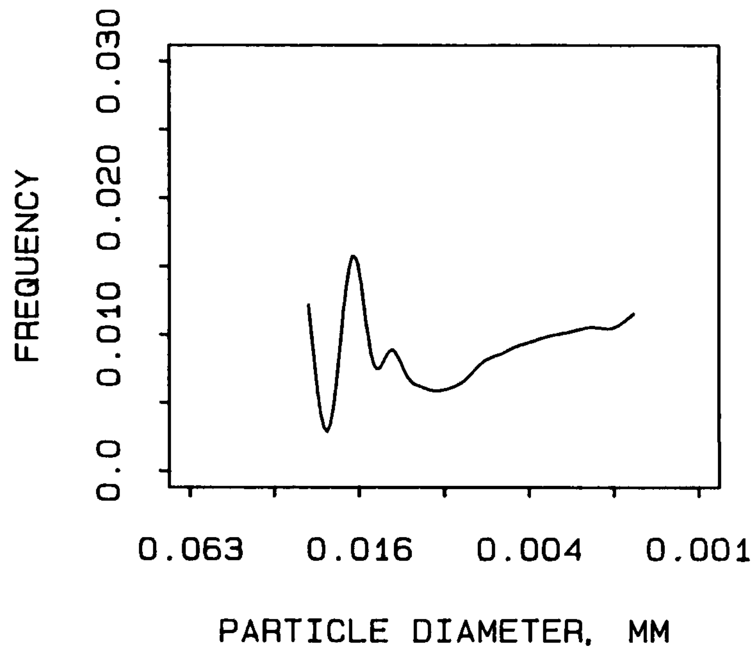
SAMPLE TYPE: Grab

DEPTH: 14.0

DATE: 9/30/91

PERCENT MOISTURE: 119





MEDIAN: 7.55 PHI, 0.0053 MM

MODE: 0.0161 MM

MEAN: 7.4 PHI, 0.0059 MM

SORTING: 1.47 PHI

SKEWNESS: -0.12

COARSEST 5%: 5.4 PHI, 0.0238 MM

% GREATER THAN 0.074 MM: 3.7

PROJECT: Tylers Beach, VA

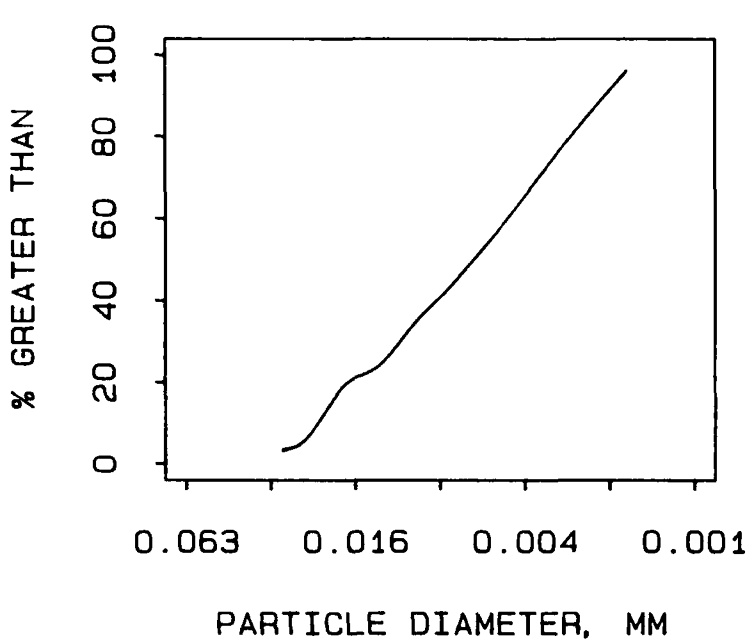
STATION: 21

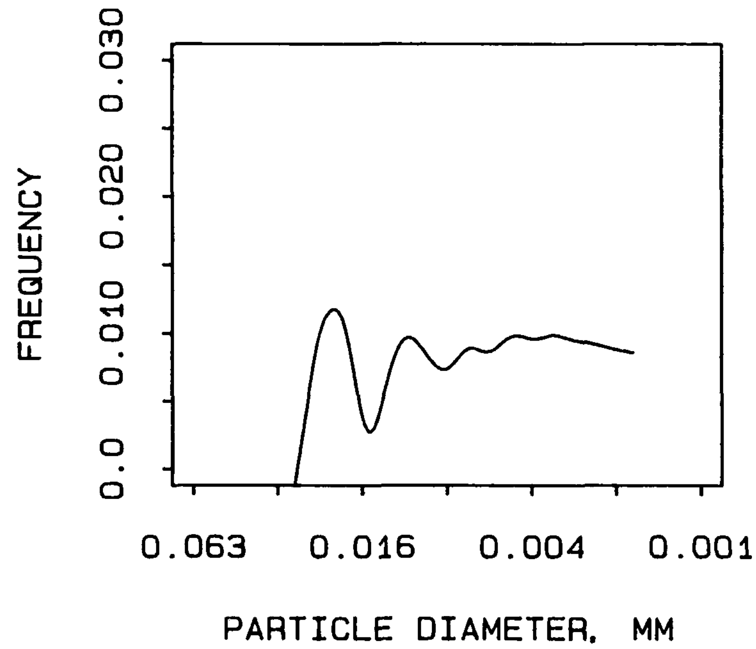
SAMPLE TYPE: Grab

DEPTH: 9.0

DATE: 9/30/91

PERCENT MOISTURE: 209





MEDIAN: 7.39 PHI, 0.006 MM

MODE: 0.0219 MM

MEAN: 7.29 PHI, 0.0064 MM

SORTING: 1.42 PHI

SKEWNESS: -0.074

COARSEST 5%: 5.4 PHI, 0.0238 MM

% GREATER THAN 0.074 MM: 0.8

PROJECT: Tylers Beach, VA

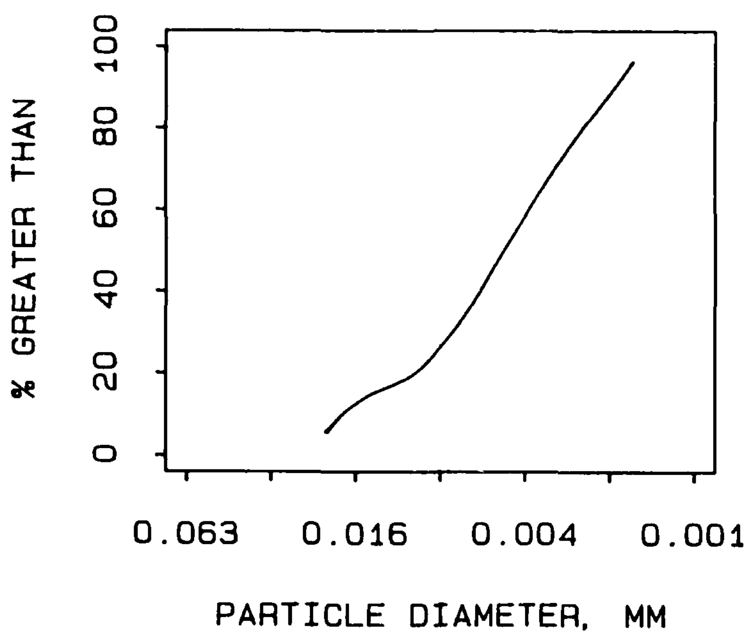
STATION: 28

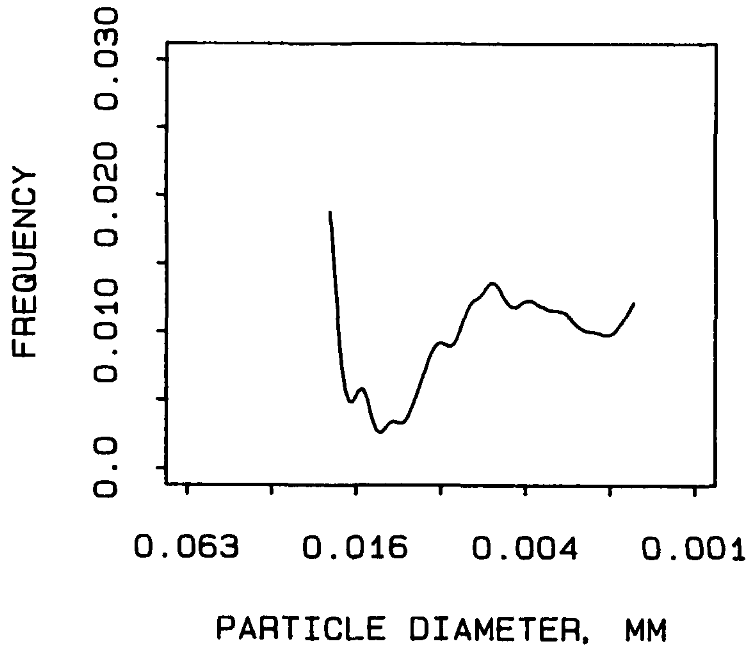
SAMPLE TYPE: Grab

DEPTH: 14.5

DATE: 9/30/91

PERCENT MOISTURE: 169





MEDIAN: 7.74 PHI, 0.0047 MM

MODE: 0.0193 MM

MEAN: 7.6 PHI, 0.0051 MM

SORTING: 1.18 PHI

SKEWNESS: -0.092

COARSEST 5%: 5.67 PHI, 0.0196 MM

% GREATER THAN 0.074 MM: 4.0

PROJECT: Tylers Beach, VA

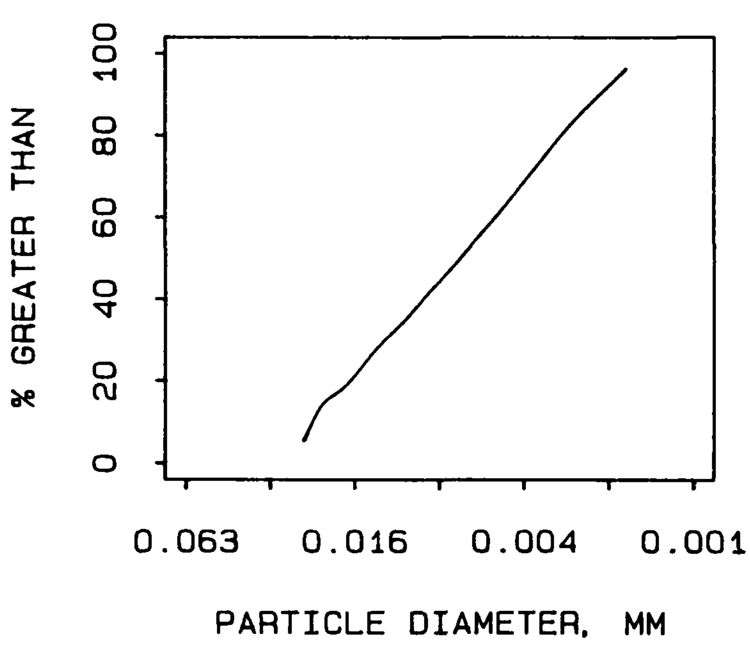
STATION: 30

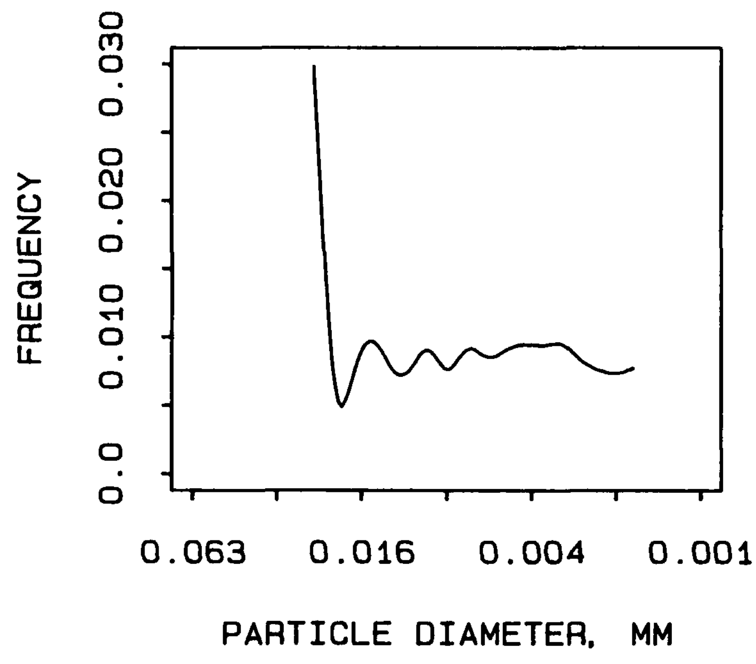
SAMPLE TYPE: Grab

DEPTH: 22.0 ft

DATE: 9/30/91

PERCENT MOISTURE: 199





MEDIAN: 7.24 PHI, 0.0066 MM

MODE: 0.0224 MM

MEAN: 7.21 PHI, 0.0068 MM

SORTING: 1.43 PHI

SKEWNESS: -0.031

COARSEST 5%: 5.41 PHI, 0.0235 MM

% GREATER THAN 0.074 MM: 5.2

PROJECT: Tylers Beach, VA

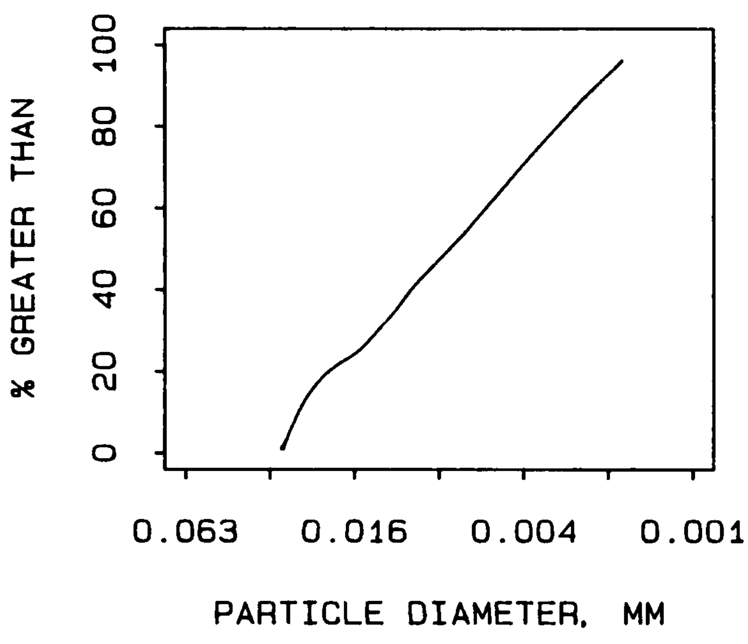
STATION: 31

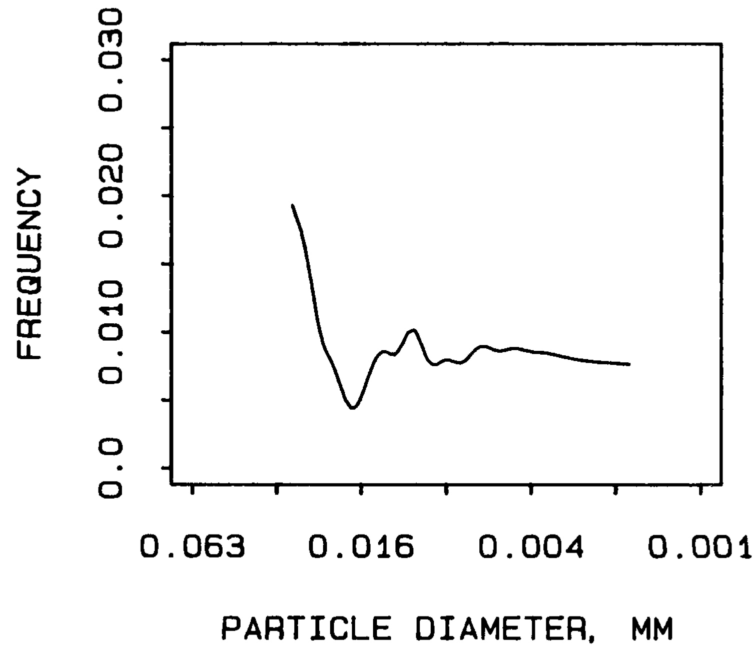
SAMPLE TYPE: Grab

DEPTH: 17.5

DATE: 9/30/91

PERCENT MOISTURE: 209





MEDIAN: 7.11 PHI, 0.0072 MM

MODE: 0.0262 MM

MEAN: 7.1 PHI, 0.0073 MM

SORTING: 1.47 PHI

SKEWNESS: -0.007

COARSEST 5%: 5.22 PHI, 0.0268 MM

% GREATER THAN 0.074 MM: 3.2

PROJECT: Tylers Beach, VA

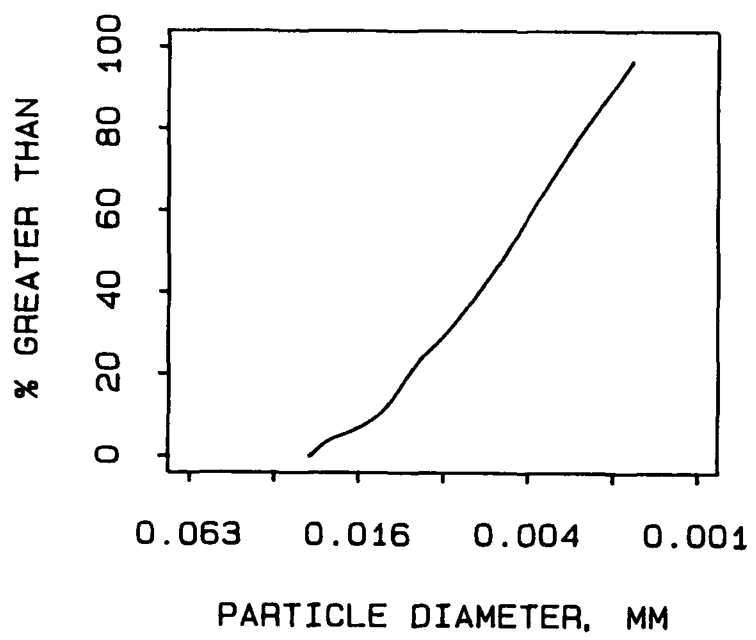
STATION: 32

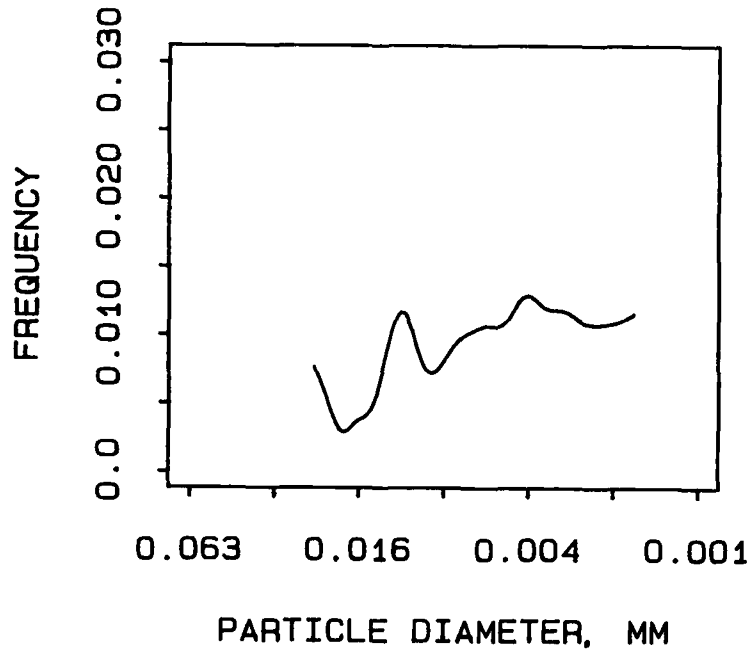
SAMPLE TYPE: Grab

DEPTH: 22.0 ft

DATE: 9/30/91

PERCENT MOISTURE: 197





MEDIAN: 7.76 PHI, 0.0046 MM

MODE: 0.0038 MM

MEAN: 7.64 PHI, 0.005 MM

SORTING: 1.16 PHI

SKEWNESS: -0.115

COARSEST 5%: 5.82 PHI, 0.0177 MM

% GREATER THAN 0.074 MM: 3.9

PROJECT: Tylers Beach, VA

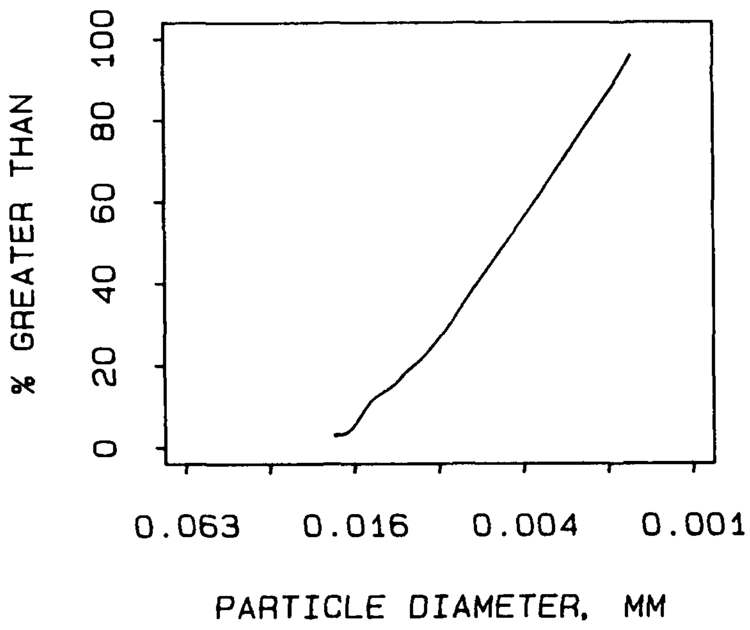
STATION: 33

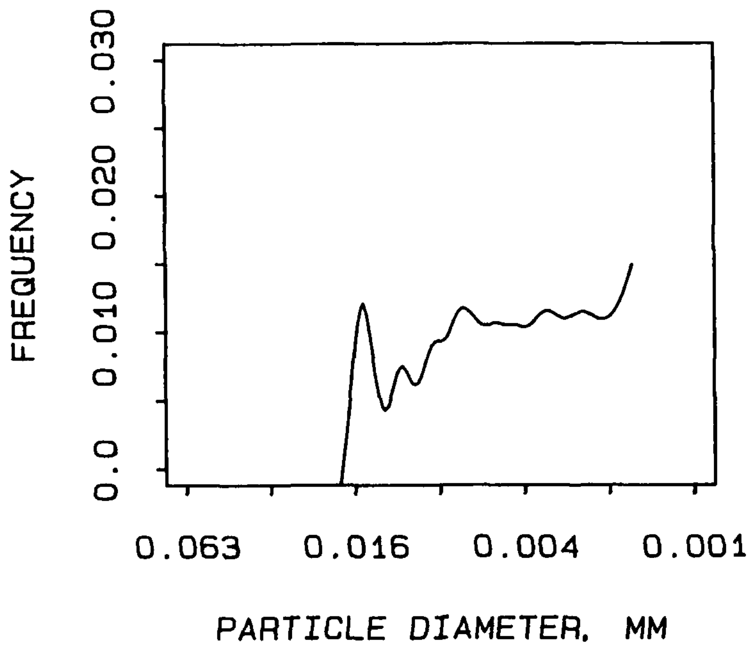
SAMPLE TYPE: Grab

DEPTH: 13.0 ft

DATE: 9/30/91

PERCENT MOISTURE: 156





MEDIAN: 7.79 PHI, 0.0045 MM

MODE: 0.0149 MM

MEAN: 7.71 PHI, 0.0048 MM

SORTING: 1.19 PHI

SKEWNESS: -0.065

COARSEST 5%: 5.99 PHI, 0.0157 MM

% GREATER THAN 0.074 MM: 7.1

PROJECT: Tylers Beach, VA

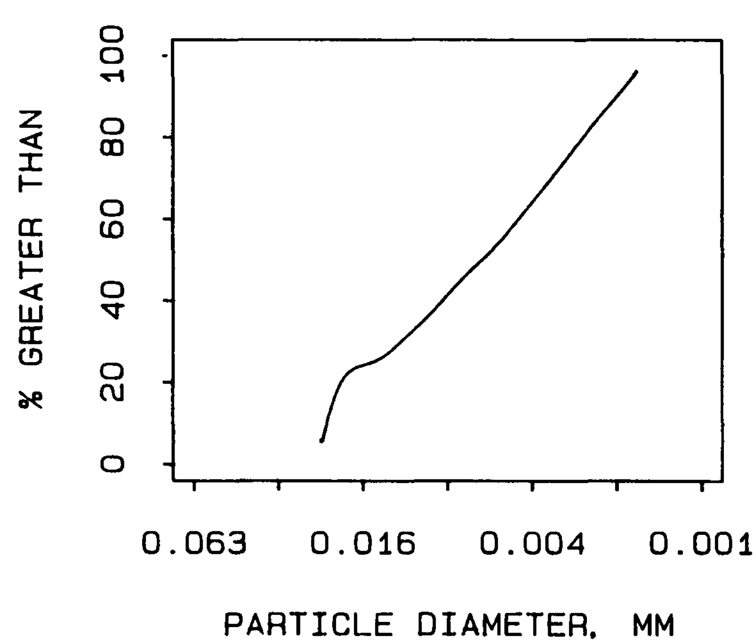
STATION: 35

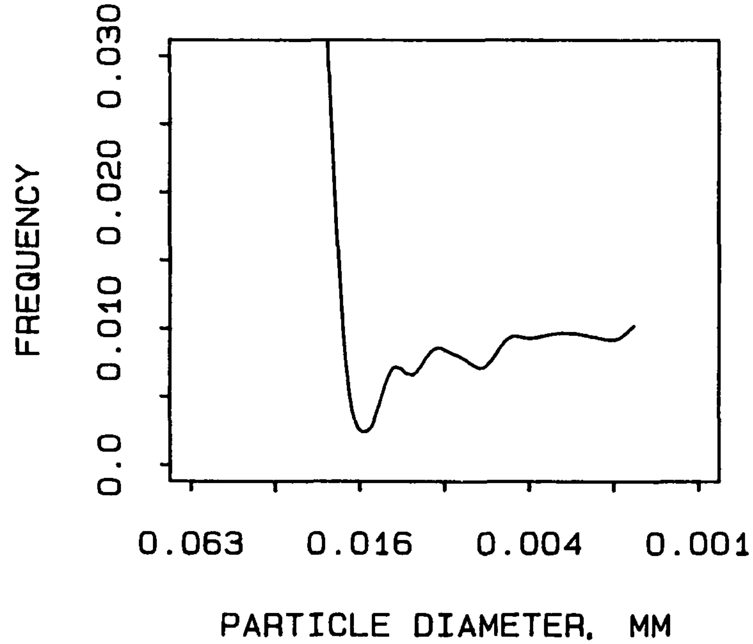
SAMPLE TYPE: Grab

DEPTH: 13.5 ft

DATE: 9/30/91

PERCENT MOISTURE: 158





MEDIAN: 7.4 PHI, 0.0059 MM

MODE: 0.0213 MM

MEAN: 7.3 PHI, 0.0063 MM

SORTING: 1.49 PHI

SKEWNESS: -0.078

COARSEST 5%: 5.52 PHI, 0.0218 MM

% GREATER THAN 0.074 MM: 30.5

PROJECT: Tylers Beach, VA

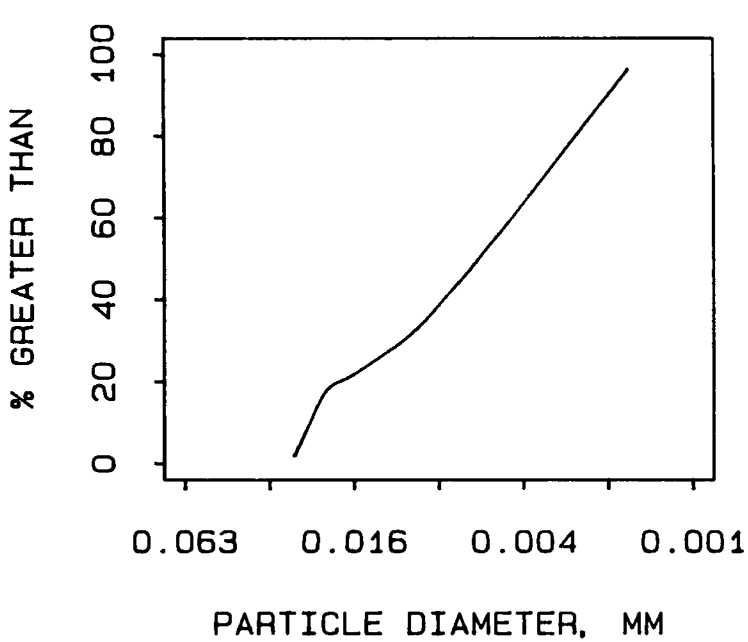
STATION: 72

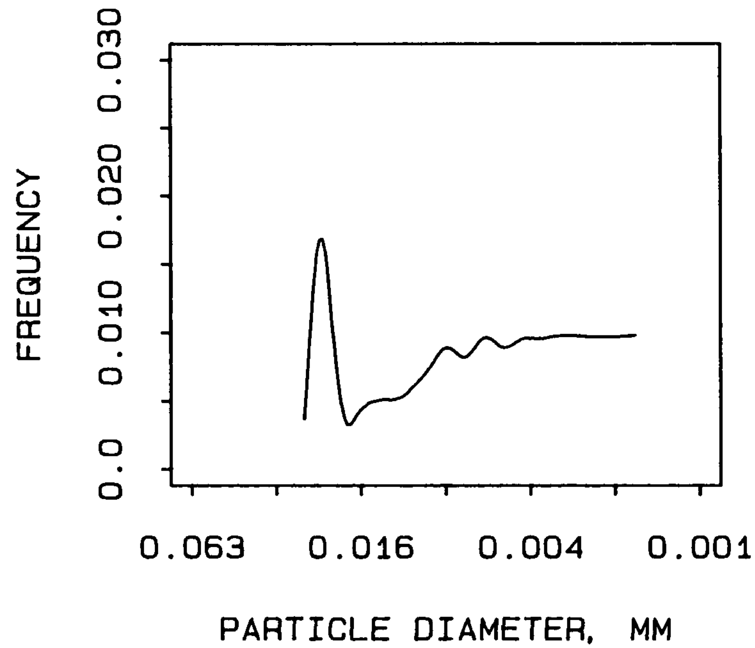
SAMPLE TYPE: Grab

DEPTH: 8.0 ft

DATE: 9/30/91

PERCENT MOISTURE: 112





MEDIAN: 7.47 PHI, 0.0057 MM

MODE: 0.0236 MM

MEAN: 7.31 PHI, 0.0063 MM

SORTING: 1.47 PHI

SKEWNESS: -0.111

COARSEST 5%: 5.36 PHI, 0.0243 MM

% GREATER THAN 0.074 MM: 3.2

PROJECT: Tylers Beach, VA

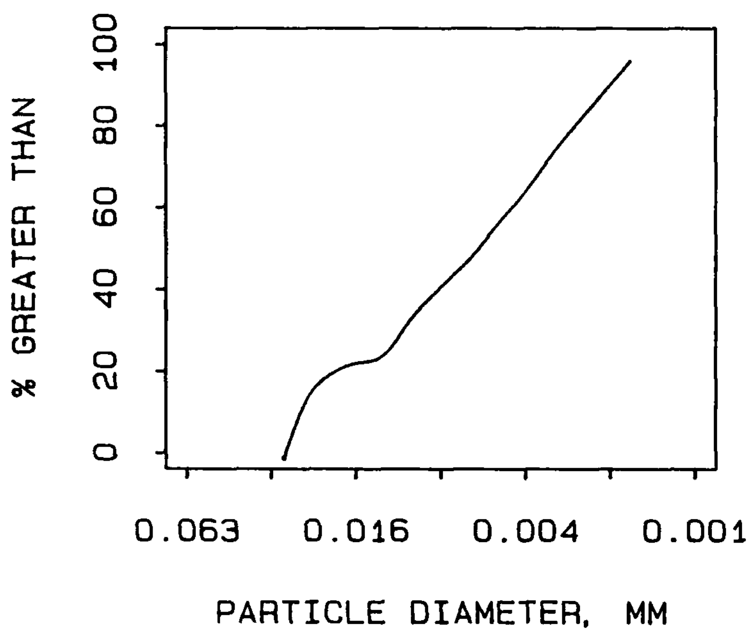
STATION: 6

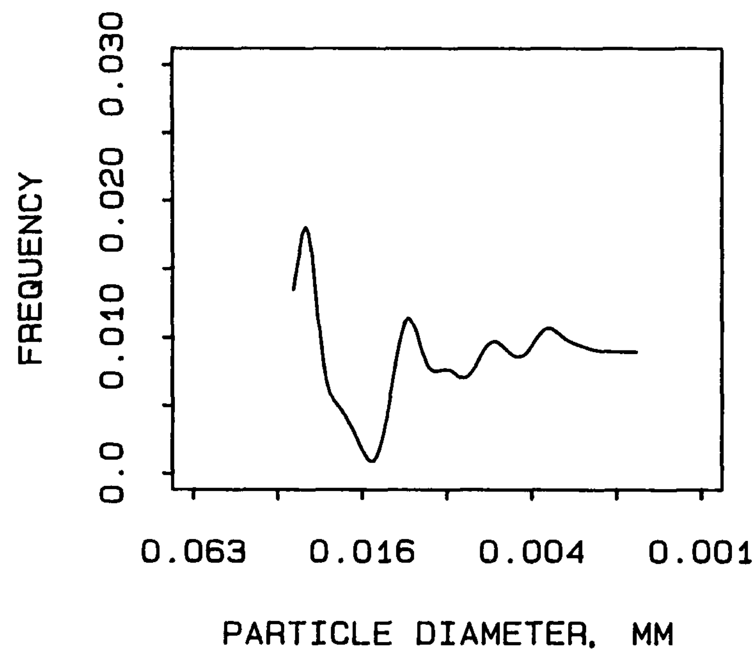
SAMPLE TYPE: Grab

DEPTH: 13.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 202





MEDIAN: 7.45 PHI, 0.0057 MM

MODE: 0.0248 MM

MEAN: 7.28 PHI, 0.0064 MM

SORTING: 1.49 PHI

SKEWNESS: -0.119

COARSEST 5%: 5.27 PHI, 0.0258 MM

% GREATER THAN 0.074 MM: 3.3

PROJECT: Tylers Beach, VA

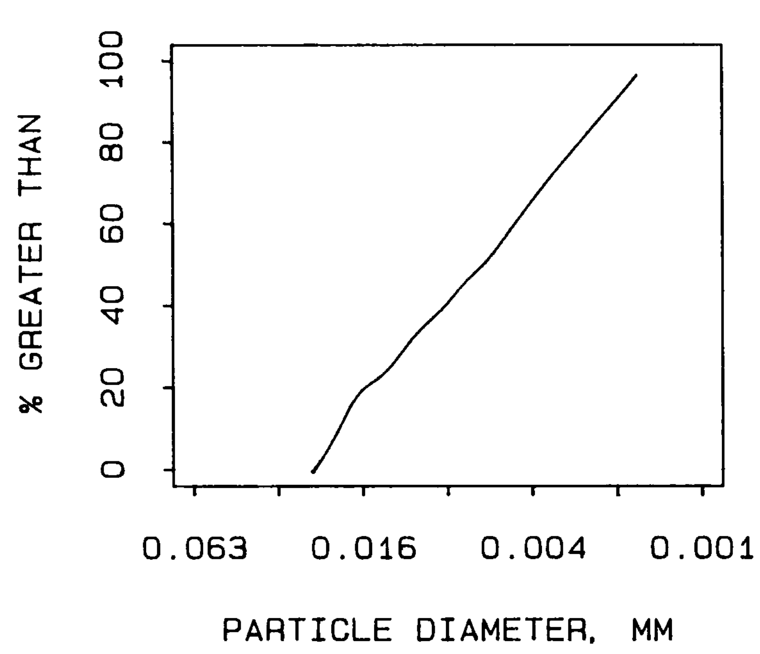
STATION: 8

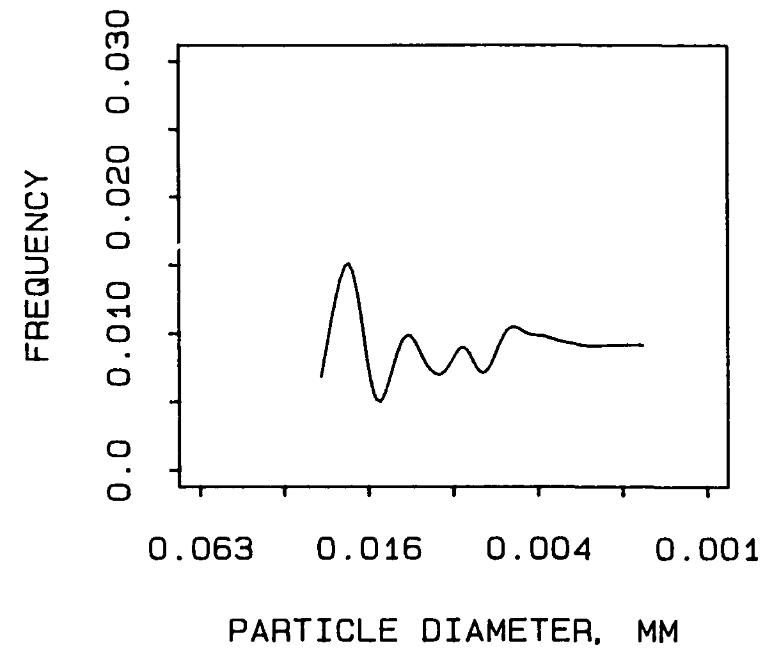
SAMPLE TYPE: Grab

DEPTH: 11.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 180





MEDIAN: 7.43 PHI, 0.0058 MM

MODE: 0.0178 MM

MEAN: 7.35 PHI, 0.0061 MM

SORTING: 1.39 PHI

SKEWNESS: -0.081

COARSEST 5%: 5.58 PHI, 0.0209 MM

% GREATER THAN 0.074 MM: 4.5

PROJECT: Tylers Beach, VA

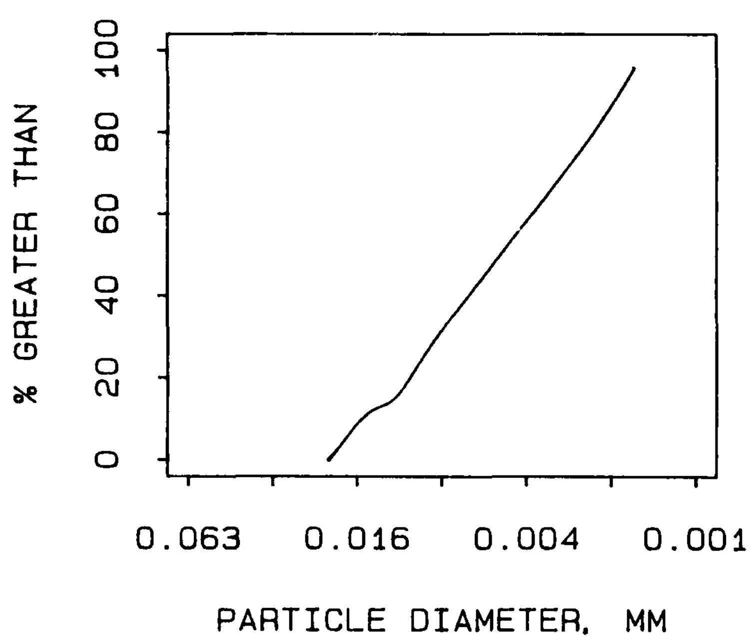
STATION: 10

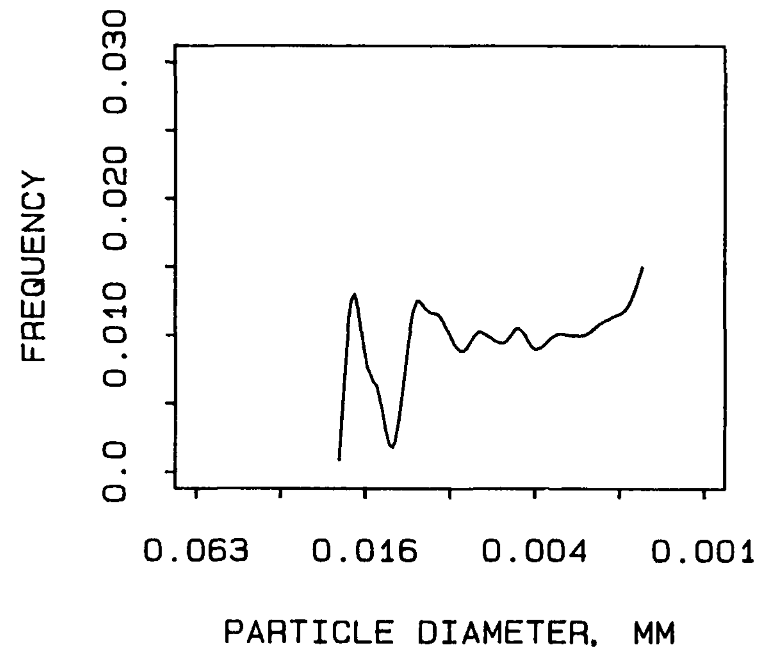
SAMPLE TYPE: Grab

DEPTH: 12.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 176





MEDIAN: 7.69 PHI, 0.0048 MM

MODE: 0.017 MM

MEAN: 7.65 PHI, 0.005 MM

SORTING: 1.25 PHI

SKEWNESS: -0.028

COARSEST 5%: 5.85 PHI, 0.0173 MM

% GREATER THAN 0.074 MM: 27.9

PROJECT: Tylers Beach, VA

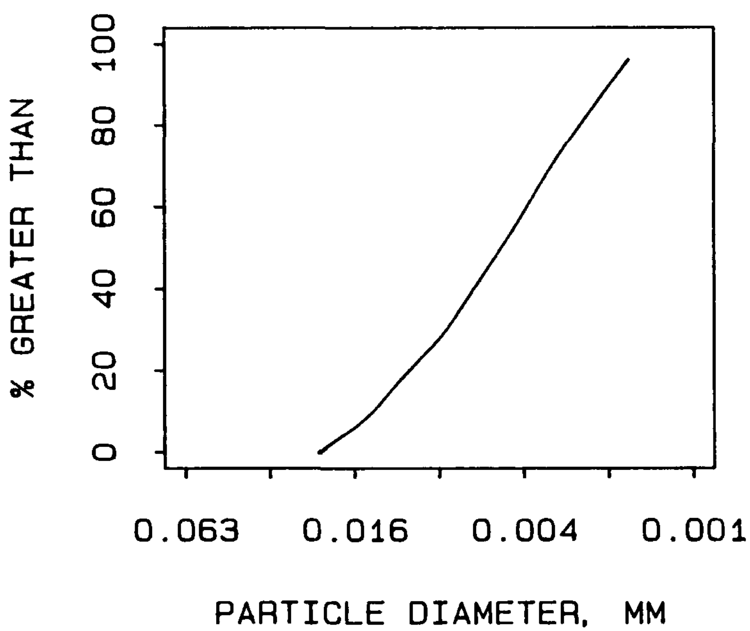
STATION: 17

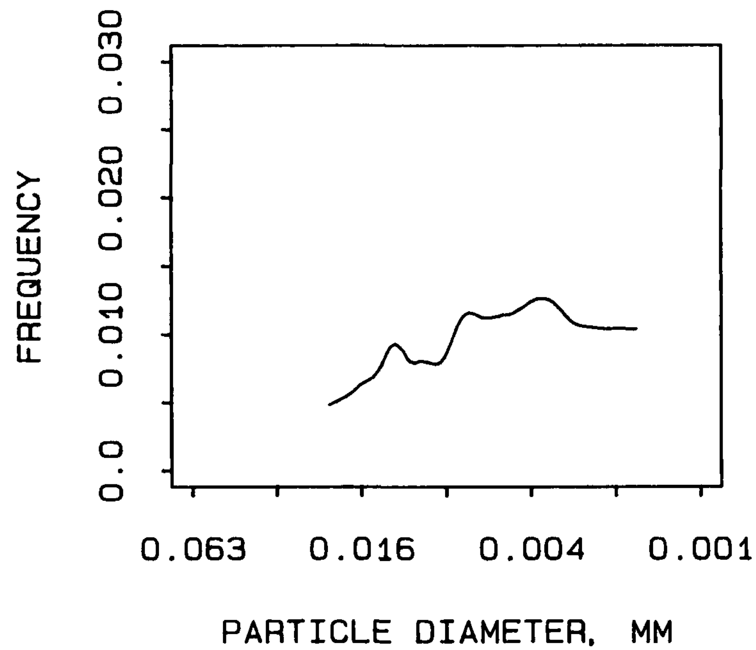
SAMPLE TYPE: Grab

DEPTH: 12.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 122





MEDIAN: 7.73 PHI, 0.0047 MM

MODE: 0.0033 MM

MEAN: 7.65 PHI, 0.005 MM

SORTING: 1.13 PHI

SKEWNESS: -0.07

COARSEST 5%: 5.96 PHI, 0.016 MM

% GREATER THAN 0.074 MM: 4.0

PROJECT: Tylers Beach, VA

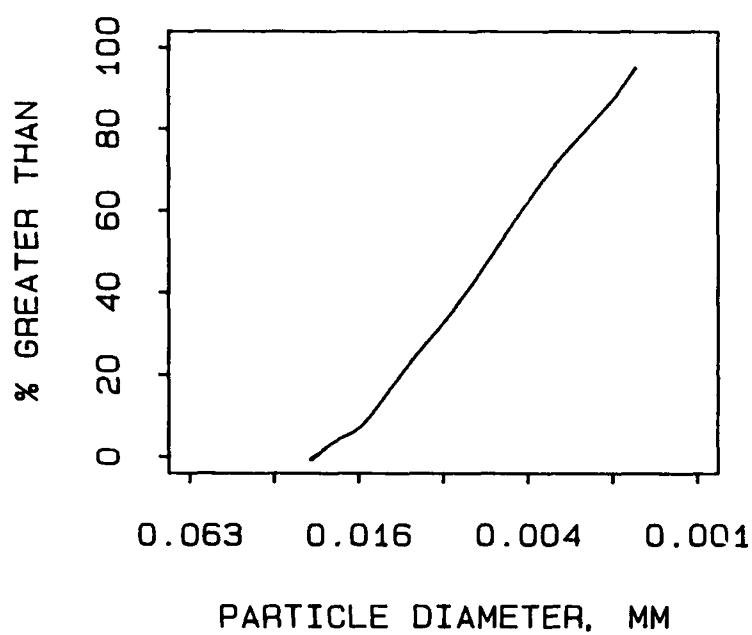
STATION: 21

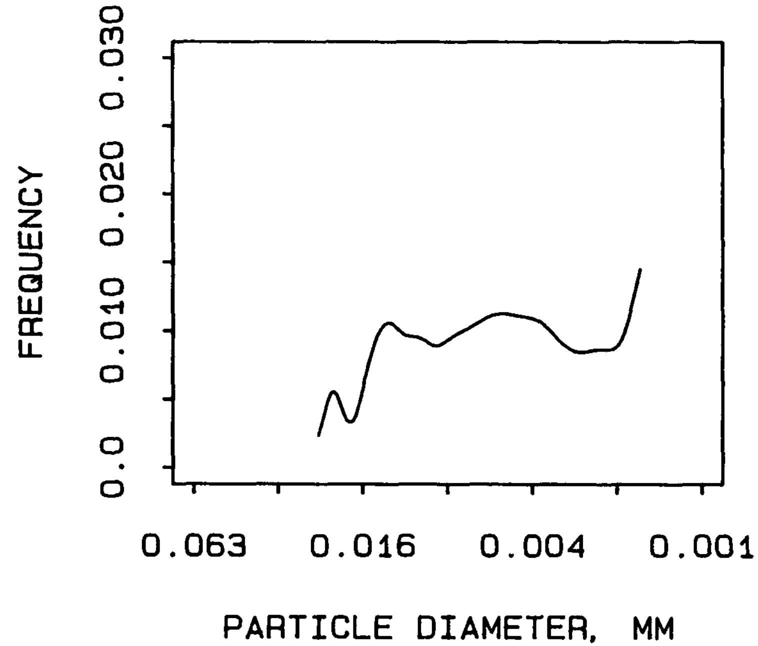
SAMPLE TYPE: Grab

DEPTH: 24.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 189





MEDIAN: 7.6 PHI, 0.0052 MM

MODE: 0.0016 MM

MEAN: 7.59 PHI, 0.0052 MM

SORTING: 1.22 PHI

SKEWNESS: -0.005

COARSEST 5%: 5.87 PHI, 0.0171 MM

% GREATER THAN 0.074 MM: 5.1

PROJECT: Tylers Beach, VA

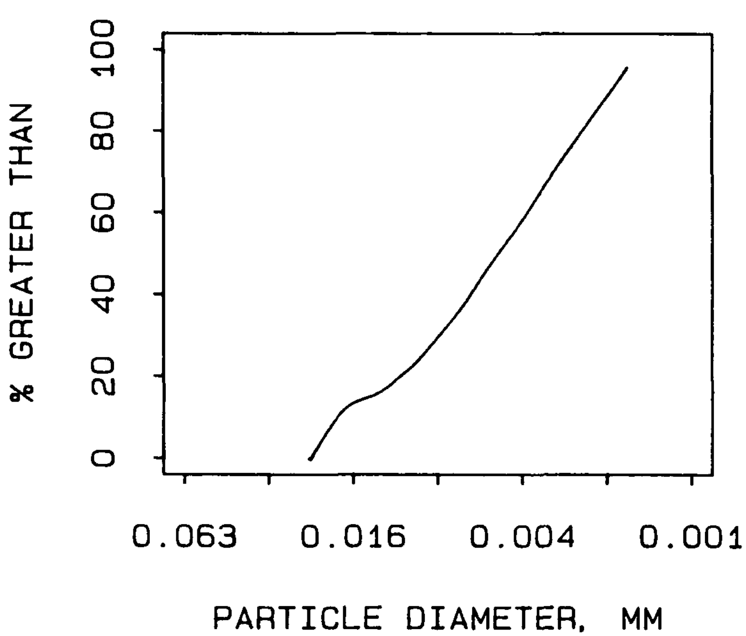
STATION: 31

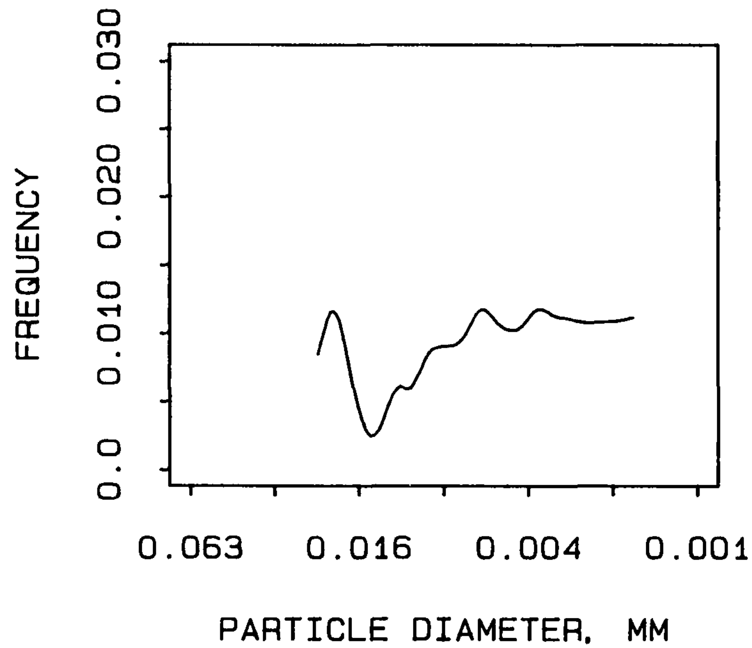
SAMPLE TYPE: Grab

DEPTH: 18.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 197





MEDIAN: 7.71 PHI, 0.0048 MM

MODE: 0.0197 MM

MEAN: 7.58 PHI, 0.0052 MM

SORTING: 1.24 PHI

SKEWNESS: -0.086

COARSEST 5%: 5.64 PHI, 0.02 MM

% GREATER THAN 0.074 MM: 9.2

PROJECT: Tylers Beach, VA

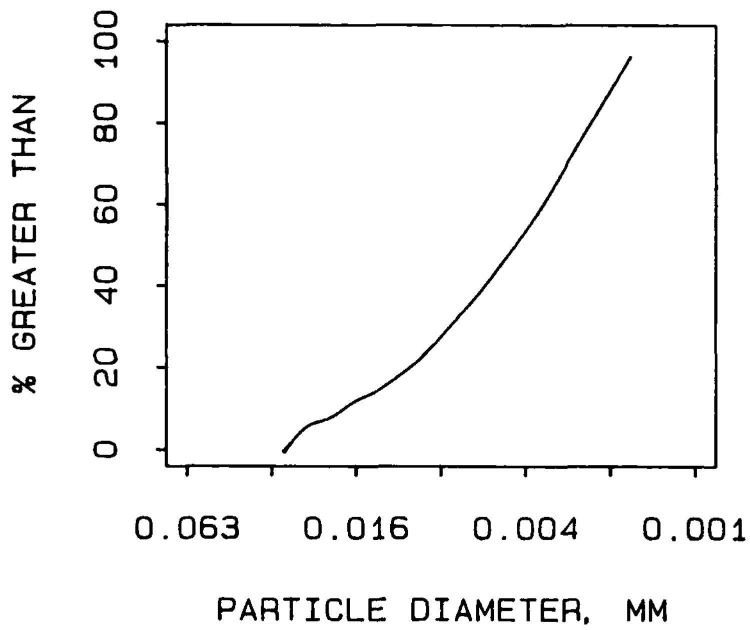
STATION: 32

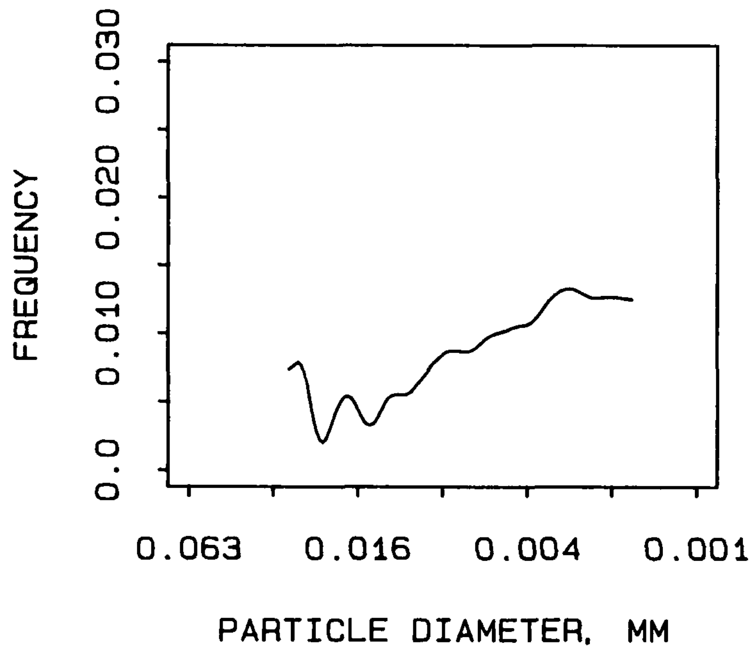
SAMPLE TYPE: Grab

DEPTH: 26.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 153





MEDIAN: 7.87 PHI, 0.0043 MM

MODE: 0.0248 MM

MEAN: 7.61 PHI, 0.0051 MM

SORTING: 1.26 PHI

SKEWNESS: -0.19

COARSEST 5%: 5.34 PHI, 0.0247 MM

% GREATER THAN 0.074 MM: 4.5

PROJECT: Tylers Beach, VA

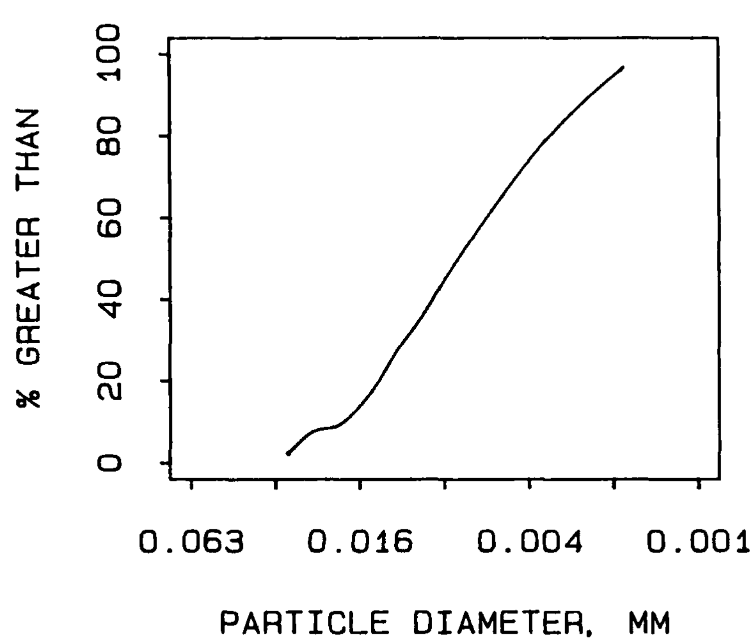
STATION: 33

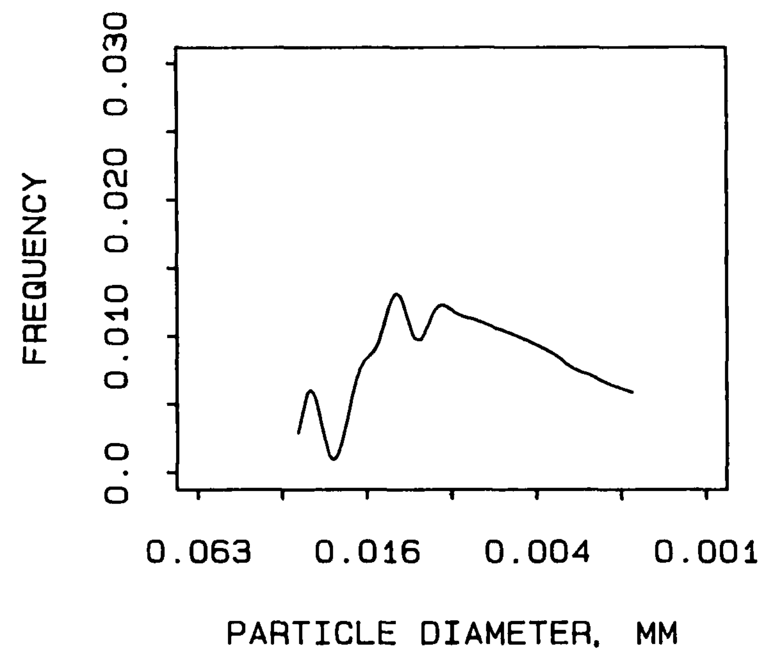
SAMPLE TYPE: Grab

DEPTH: 14.0 ft

DATE: 10/2/91

PERCENT MOISTURE: 158





MEDIAN: 7.17 PHI, 0.007 MM

MODE: 0.0255 MM

MEAN: 7.21 PHI, 0.0068 MM

SORTING: 1.19 PHI

SKEWNESS: 0.047

COARSEST 5%: 5.27 PHI, 0.0259 MM

% GREATER THAN 0.074 MM: NA

PROJECT: Tylers Beach, VA

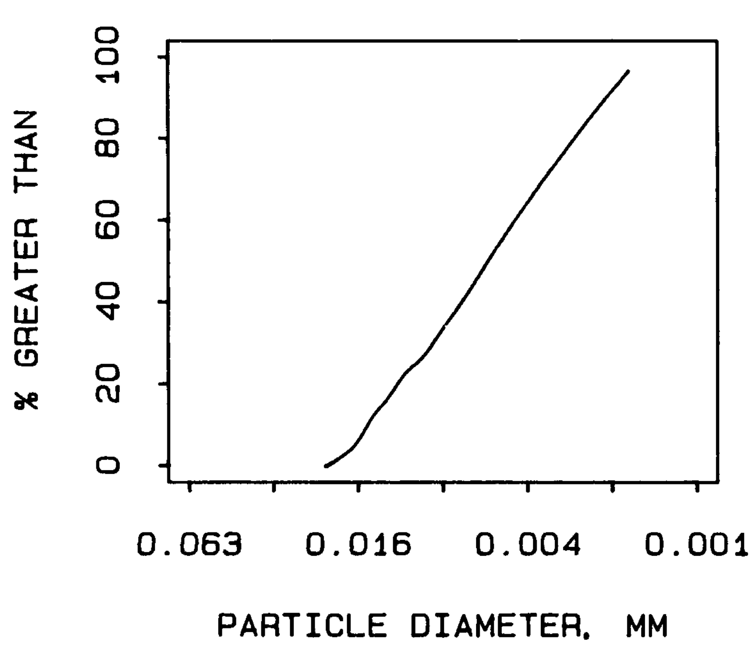
STATION: Discharge Point

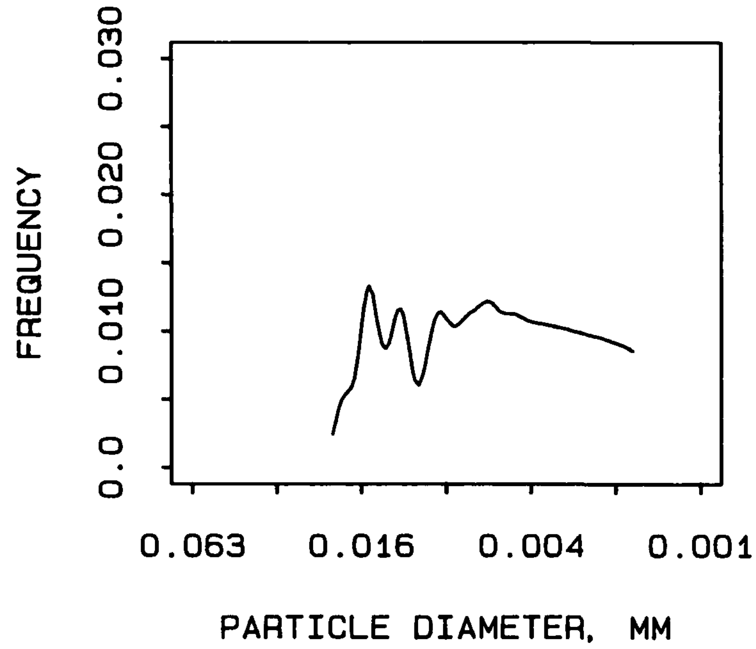
SAMPLE TYPE: Pipeline Slurry

DEPTH: -

DATE: 10/1/91

PERCENT MOISTURE: ~2000





MEDIAN: 7.53 PHI, 0.0054 MM

MODE: 0.0147 MM

MEAN: 7.53 PHI, 0.0054 MM

SORTING: 1.15 PHI

SKEWNESS: 0.008

COARSEST 5%: 5.98 PHI, 0.0159 MM

% GREATER THAN 0.074 MM: NA

PROJECT: Tylers Beach, VA

STATION: Discharge Point

SAMPLE TYPE: Pipeline Slurry

DEPTH: -

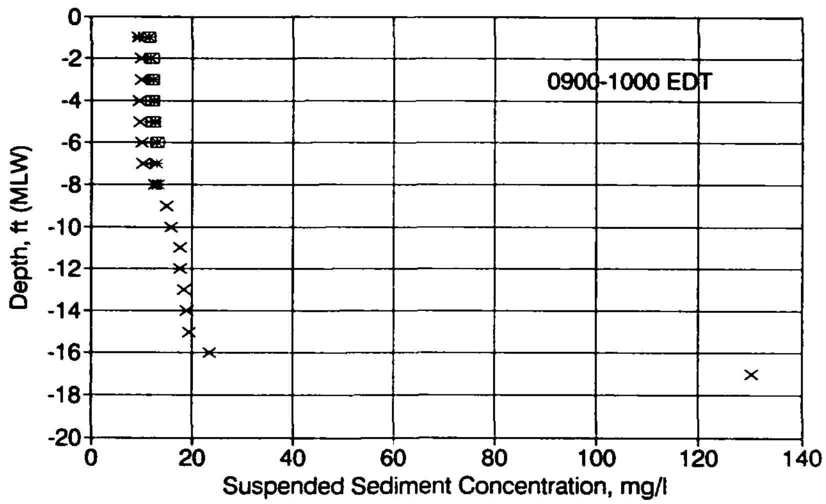
DATE: 10/1/91

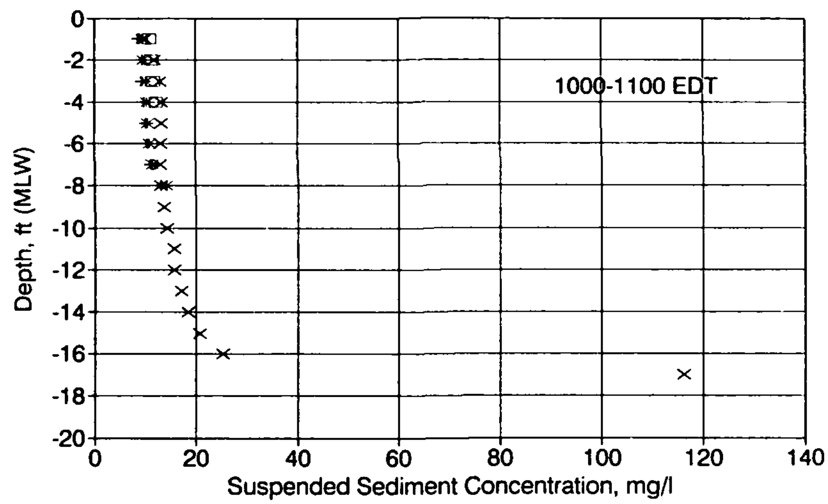
PERCENT MOISTURE: ~2000

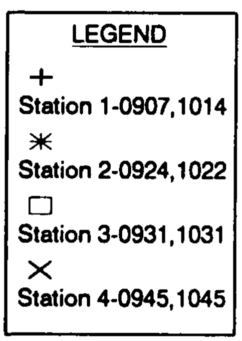
APPENDIX D: TRANSMISSOMETER CONCENTRATION PROFILES[1]

Transmissivity measurements taken at four stations on 1 and 2 October, during dredging and placement operations at Tylers Beach, were converted to suspended material concentration using Equation 2 of this report. Vertical profiles of the calculated suspended material concentration are presented.

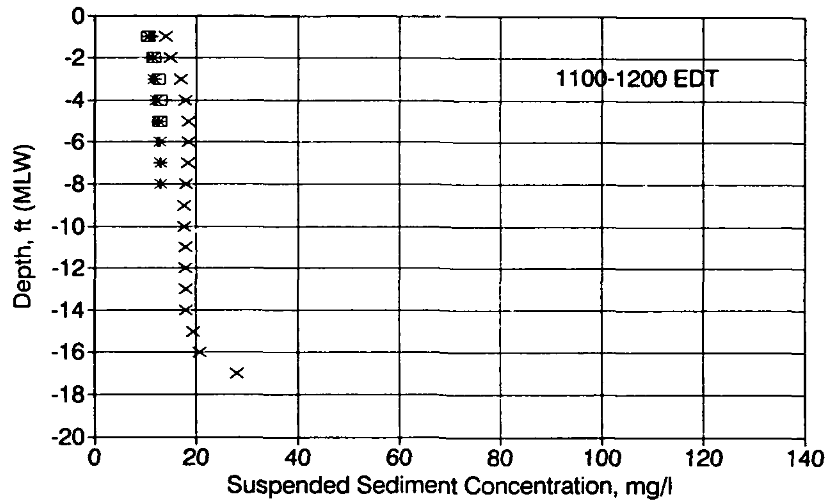
[1]Written by Mses. Michelle M. Thevenot and Terri L. Prickett.

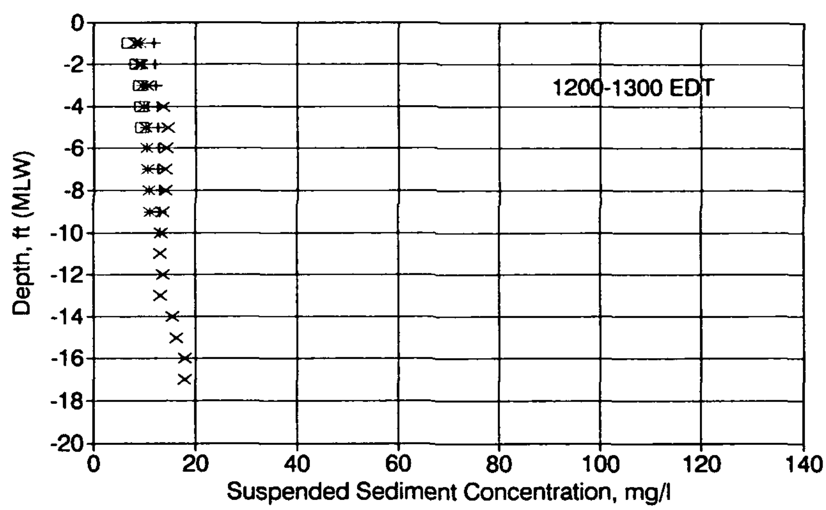






TRANSMISSOMETER DATA
0900-1100 EDT
1 OCTOBER 1991





LEGEND

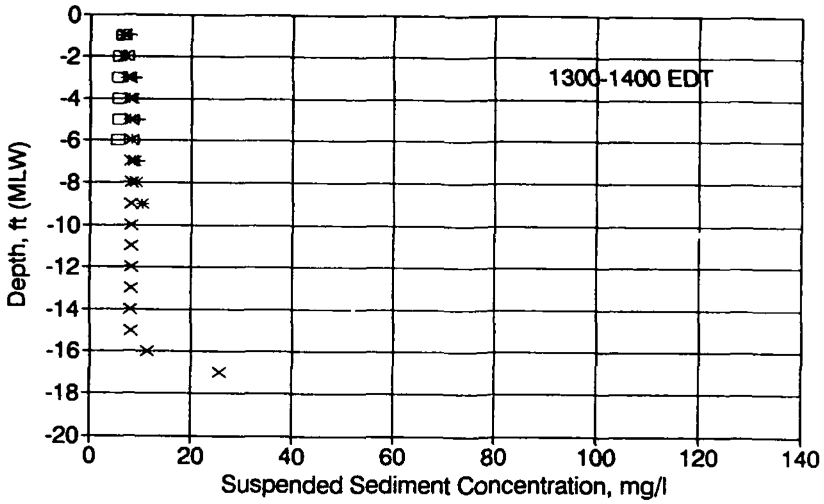
+ Station 1-1102,1205

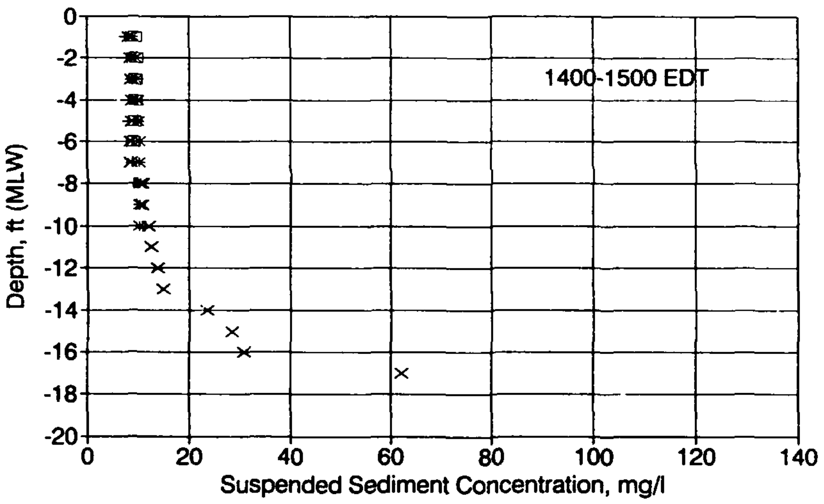
✳ Station 2-1111,1216

□ Station 3-1116,1222

× Station 4-1132,1238

TRANSMISSOMETER DATA
1100-1300 EDT
1 OCTOBER 1991





LEGEND

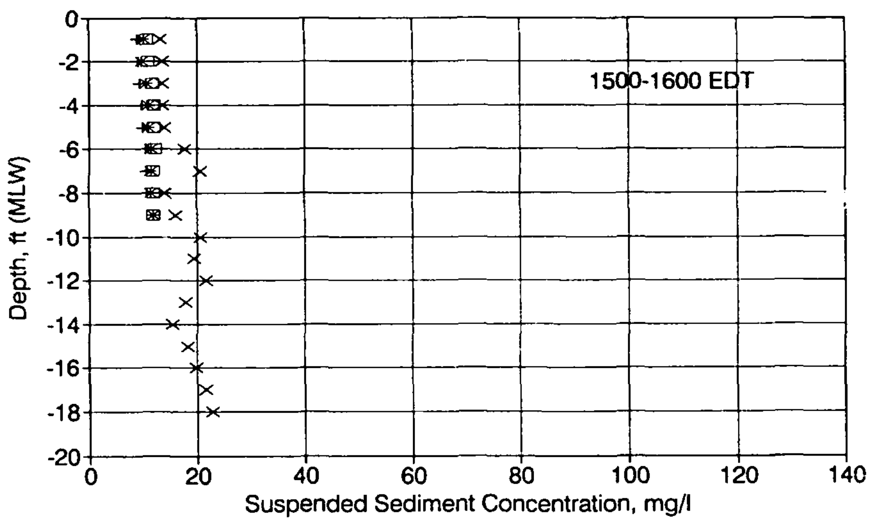
+ Station 1-1302,1410

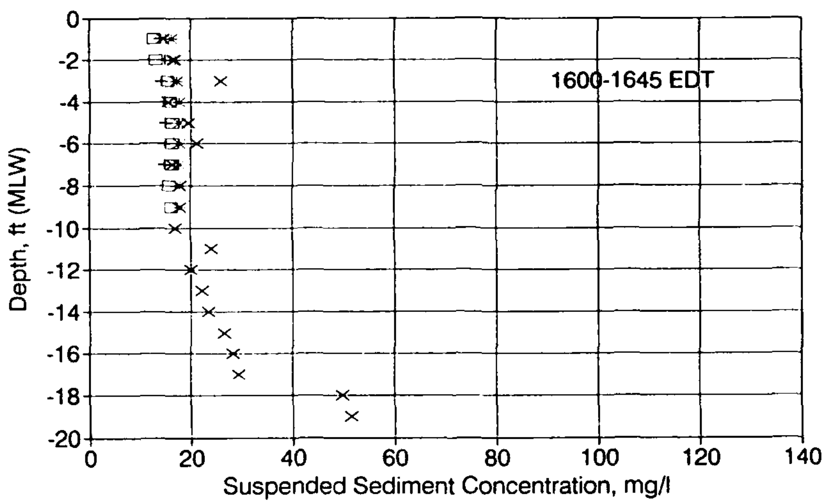
✳ Station 2-1312,1416

□ Station 3-1320,1428

× Station 4-1330,1439

TRANSMISSOMETER DATA
1300-1500 EDT
1 OCTOBER 1991





LEGEND

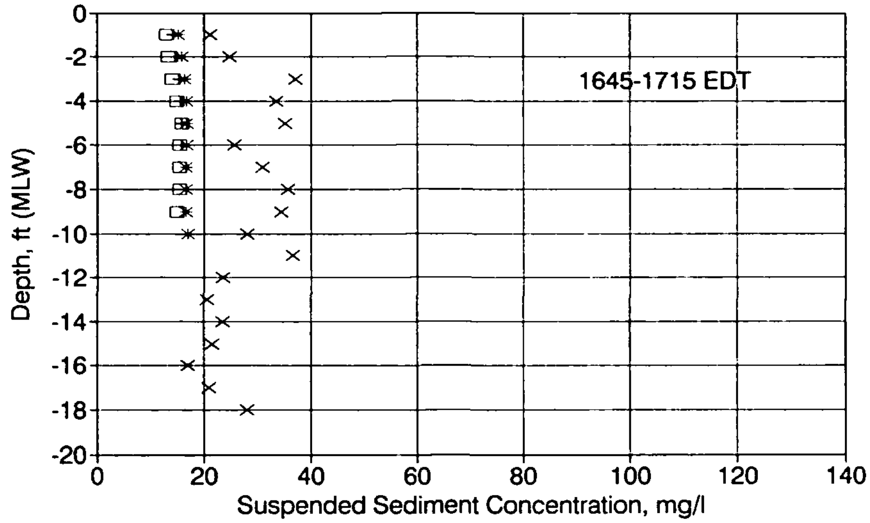
+ Station 1-1507,1604

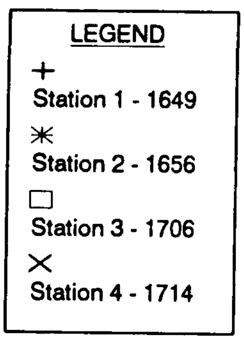
✳ Station 2-1517,1612

□ Station 3-1528,1625

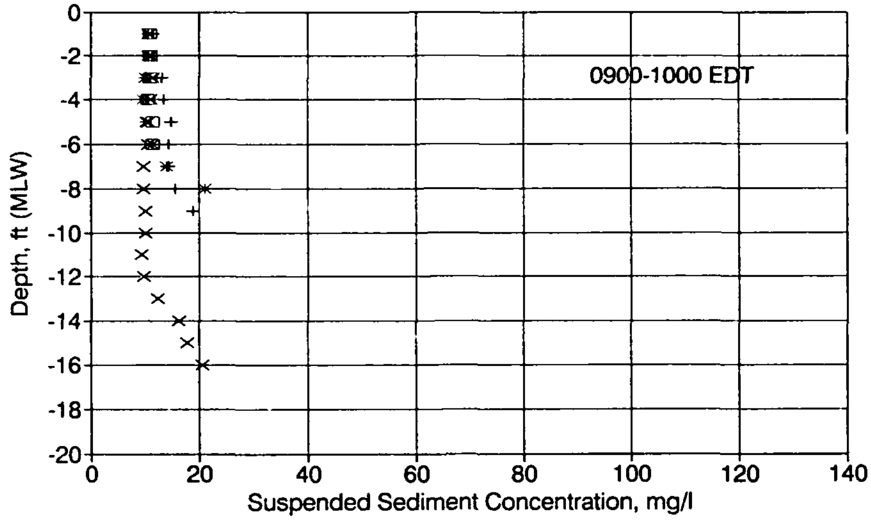
× Station 4-1537,1632

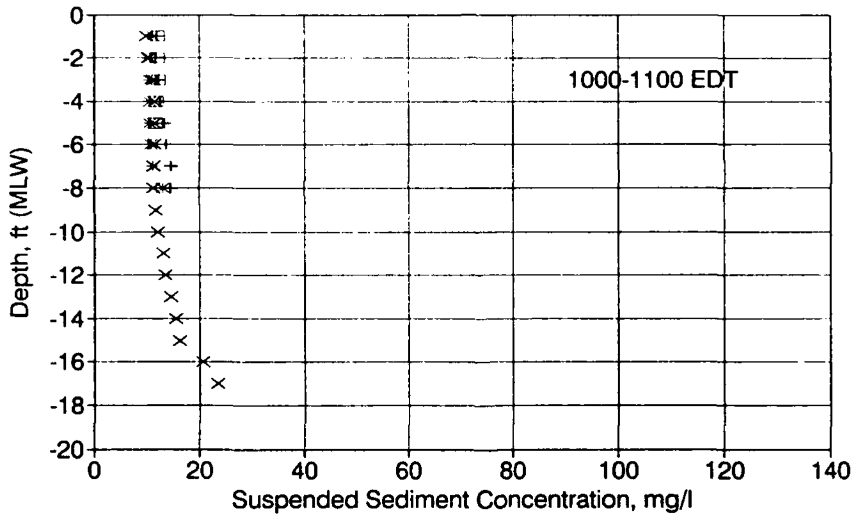
TRANSMISSOMETER DATA
1500-1645 EDT
1 OCTOBER 1991





TRANSMISSOMETER DATA
1645-1715 EDT
1 OCTOBER 1991





LEGEND

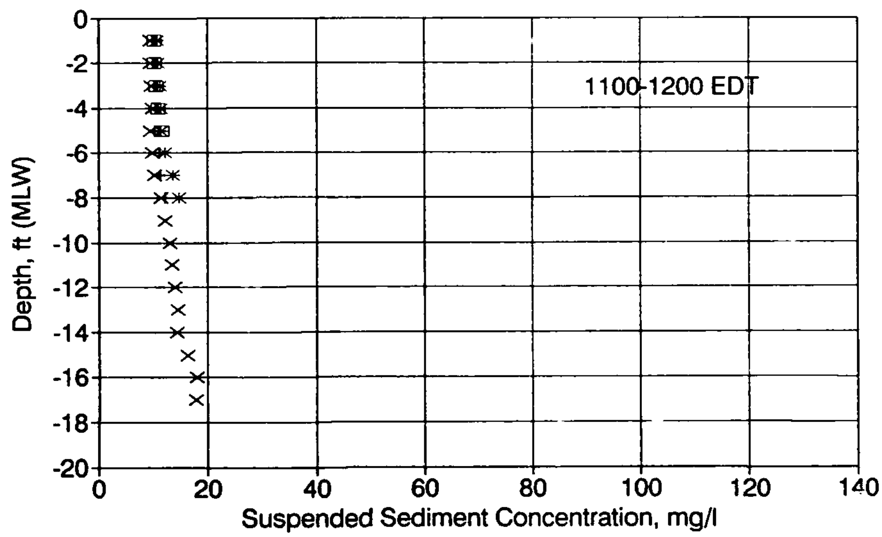
+ Station 1-0919,1005

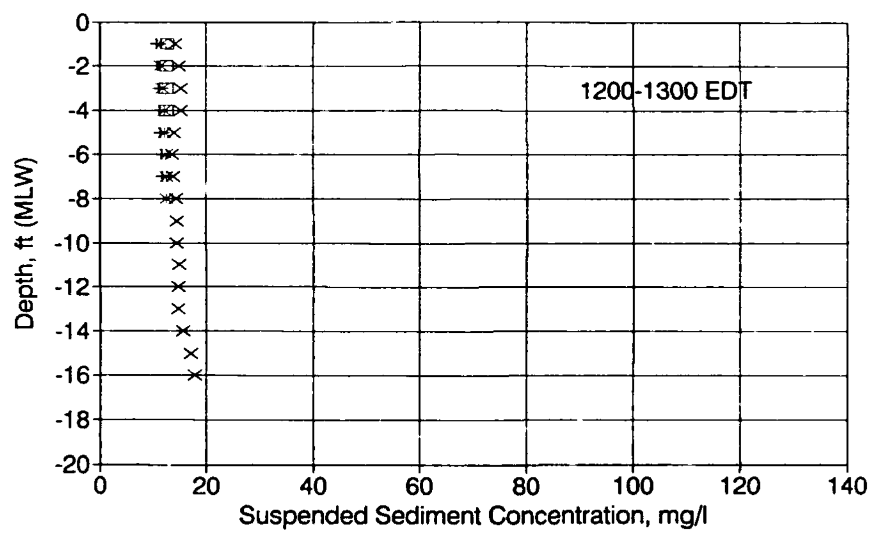
✳ Station 2-0932,1015

□ Station 3-0937,1022

× Station 4-0947,1037

TRANSMISSOMETER DATA
0900-1100 EDT
2 OCTOBER 1991





LEGEND

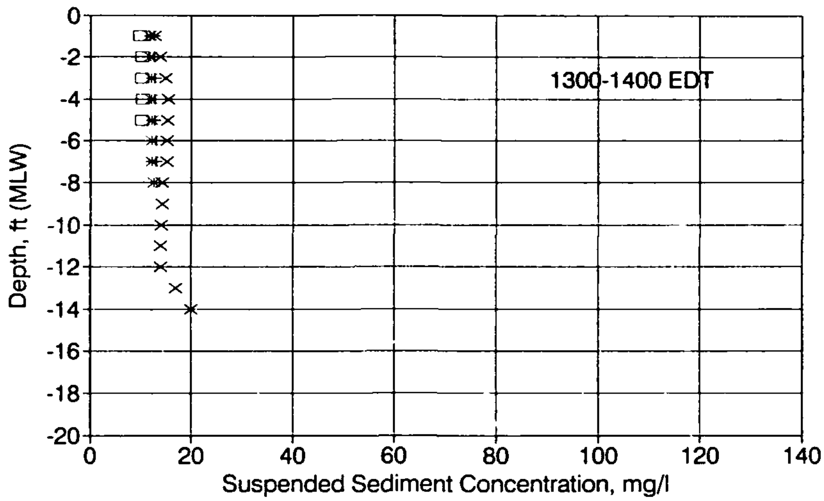
+ Station 1-1114,1206

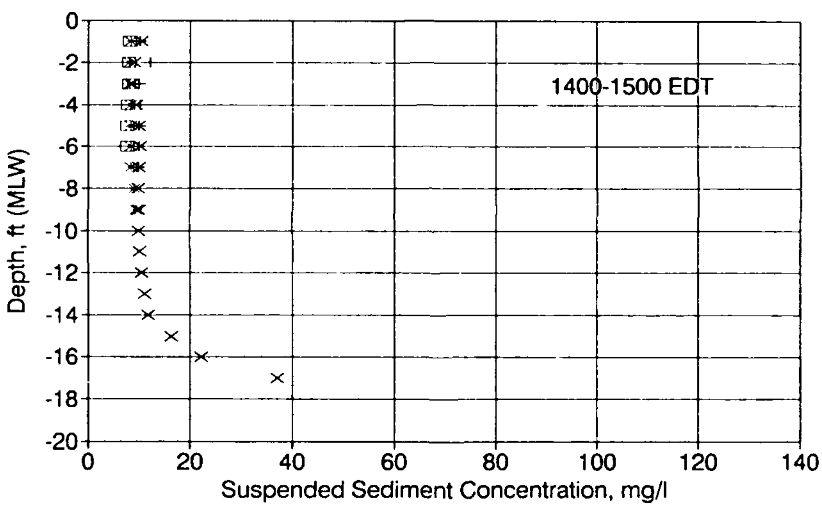
✳ Station 2-1122,1213

□ Station 3-1128,1219

✕ Station 4-1137,1226

TRANSMISSOMETER DATA
1100-1300 EDT
2 OCTOBER 1991





LEGEND

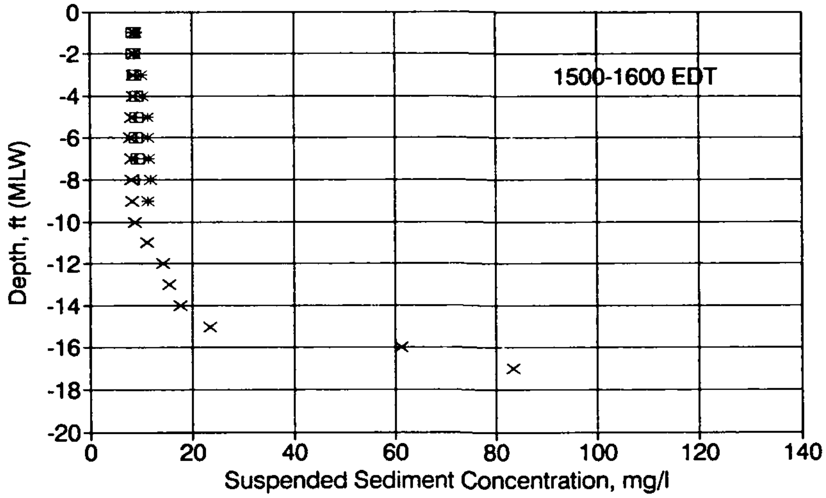
+ Station 1-1304,1404

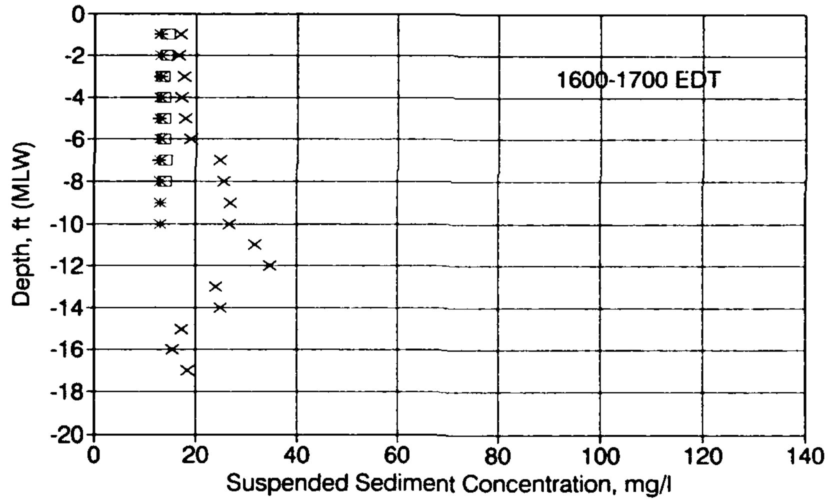
✳ Station 2-1309,1412

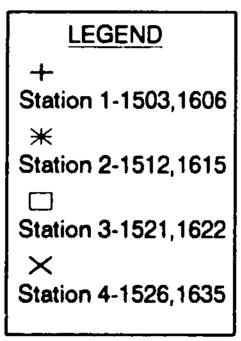
□ Station 3-1316,1418

× Station 4-1325,1425

TRANSMISSOMETER DATA
1300-1500 EDT
2 OCTOBER 1991







TRANSMISSOMETER DATA
1500-1700 EDT
2 OCTOBER 1991

APPENDIX E: ACOUSTIC SURVEY LOCATION MAPS[1]

The acoustic surveys summarized in this report are comprised of individual transects. Each transect is referred to as a leg, in keeping with the terminology established during monitoring and used in the field notes. Table E1 lists the starting and ending times for the logs of each survey. In the case of the background surveys, which were directed approximately north to south along the channel, the same legs were monitored repeatedly and numbered by location; Leg 1 was located close to shore, Leg 2 was located down the center line of the channel, and Leg 3 was located along Point of Shoals. During plume surveys the legs were run approximately east to west across the channel and are numbered in spatial sequence. In organizing the legs within individual plume surveys, the numbering was based on a spatial and not a temporal system. Therefore, some leg numbers run opposite to the direction of time, but this facilitates analysis of the data within individual surveys and comparison of data from different surveys. By ordering the legs from north to south, results can be compared from different tidal phases without considering individual survey directions. To preserve the accuracy of horizontal position in plotting concentration data from acoustic backscatter intensity profiles taken during the surveys, positions for each leg were projected onto a straight line course (indicated with dashed lines). Each map shows an average current vector U. Because all legs in each plume survey were collected sequentially over a short period of time, a constant current was assumed over all legs. The survey maps contained in this appendix are referenced to the discharge point, which was located at 274,350 ft North and 2,539,300 ft East VSPC.

[1]Written by Messrs. Craig A. Huhta and Ramon G. Cabrera and Ms. Terri L. Prickett.

Table E1

Starting and Ending Times for Survey Legs

Date Month/Day	Survey Number	Leg Number	Leg Start Time EDT*	Leg End Time EDT
09/30	1	2	09:53:36	10:20:35
	2	1	12:30:36	13:16:00
	3	2	13:54:07	14:31:39
		3	14:49:20	15:27:08
		2	15:49:45	16:13:06
		1	16:20:00	17:04:02
10/01	4	1	09:46:24	09:49:26
		2	09:50:40	09:54:01
		3	09:55:01	09:57:50
		4	09:58:31	10:01:01
		5	10:03:03	10:04:49
		6	10:05:07	10:06:55
		7	10:09:20	10:19:11
		8	10:19:48	10:22:12
	5	6	11:21:02	11:22:52
		5	11:25:07	11:27:26
		4	11:29:11	11:31:02
		3	11:34:39	11:36:55
		2	11:39:54	11:42:10
		1	11:42:39	11:45:20
	6	6	13:15:21	13:17:33
		5	13:18:32	13:20:40
		4	13:24:34	13:25:26
		3	13:28:13	13:30:33
		2	13:33:32	13:36:37
		1	13:37:04	13:39:30

(Continued)

*Eastern Daylight Time.

(Sheet 1 of 3)

Table E1 (Continued)

Date Month/Day	Survey Number	Leg Number	Leg Start Time EDT	Leg End Time EDT
10/01	7	1	17:18:26	17:22:00
		2	17:23:41	17:28:44
		3	17:30:29	17:33:41
		4	17:34:42	17:37:54
		5	17:40:52	17:43:05
		6	17:43:57	17:45:28
		7	17:50:25	17:52:49
10/02	8	7	12:40:04	12:43:00
		6	12:44:40	12:47:45
		5	12:49:26	12:52:12
		4	12:53:02	12:55:50
		3	12:56:57	12:59:49
		2	13:00:41	13:02:27
		1	13:15:03	13:17:12
	9	6	13:43:11	13:46:33
		5	13:48:11	13:50:54
		4	13:52:43	13:55:47
		3	14:00:18	14:02:59
		2	14:04:56	14:07:58
		1	14:10:23	14:12:13
	10	1	16:09:24	16:11:55
		2	16:12:58	16:15:30
		3	16:16:52	16:18:03
		4	16:20:56	16:22:39
		5	16:24:09	16:26:21
		6	16:27:19	16:29:22
		7	16:30:40	16:32:36
		8	16:33:38	16:35:23
		9	16:36:55	16:38:38
		10	16:39:36	16:41:04
		11	16:41:51	16:43:23
		12	16:44:36	16:45:45

(Continued)

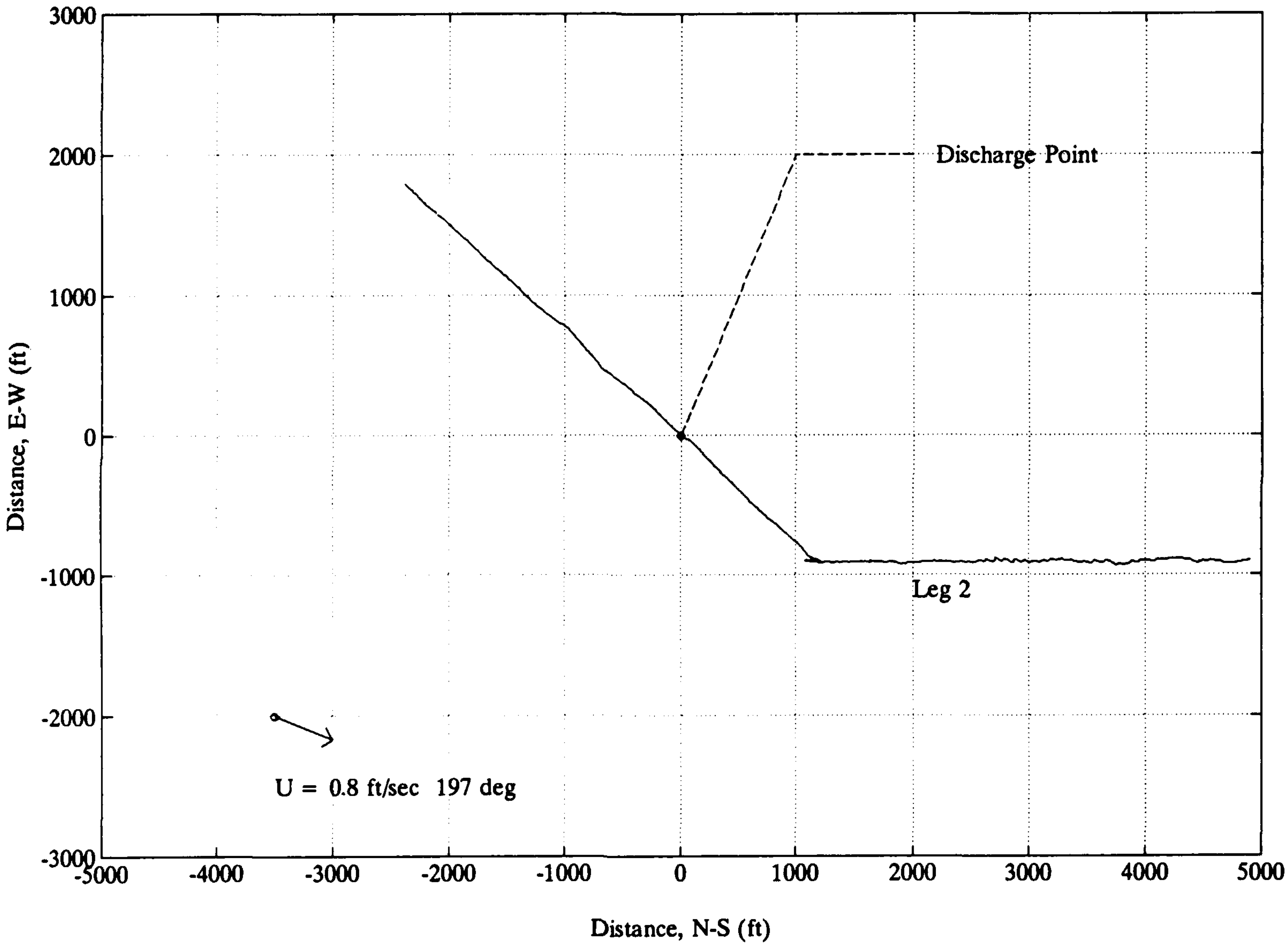
(Sheet 2 of 3)

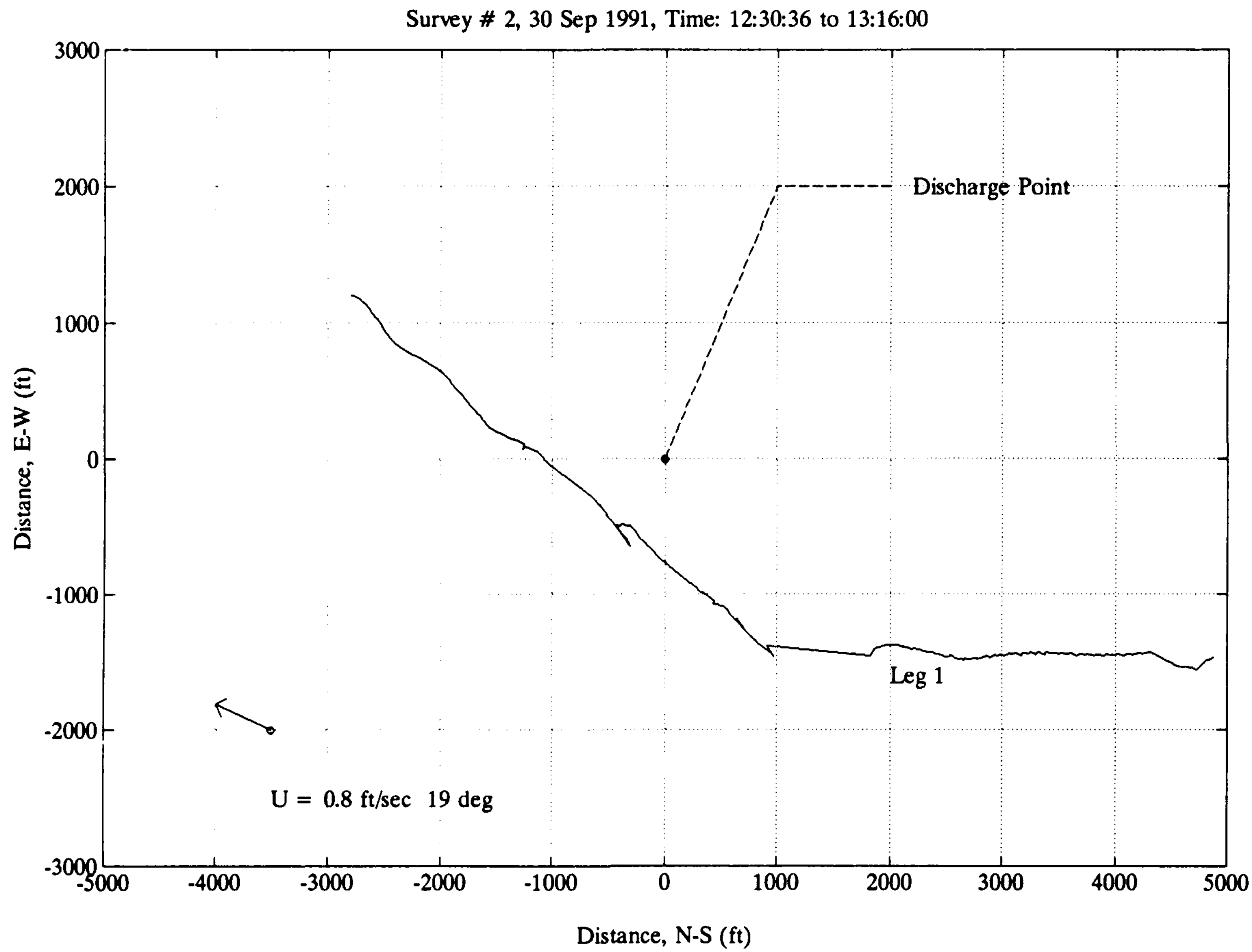
Table E1 (Concluded)

Date Month/Day	Survey Number	Leg Number	Leg Start Time EDT	Leg End Time EDT
10/02	11	1	17:23:20	17:26:46
		2	17:28:12	17:30:58
		3	17:32:19	17:35:25
		4	17:36:37	17:39:26
		5	17:40:46	17:43:45
10/3	12	1	10:07:51	10:10:53
		2	10:12:39	10:15:35
		3	10:17:51	10:19:49
		4	10:21:29	10:24:15
		5	10:26:45	10:27:53
		6	10:29:32	10:32:03
		7	10:33:28	10:35:25
		8	10:36:25	10:38:27
		9	10:40:04	10:41:54
		10	10:42:54	10:44:38
		11	10:45:58	10:47:48

(Sheet 3 of 3)

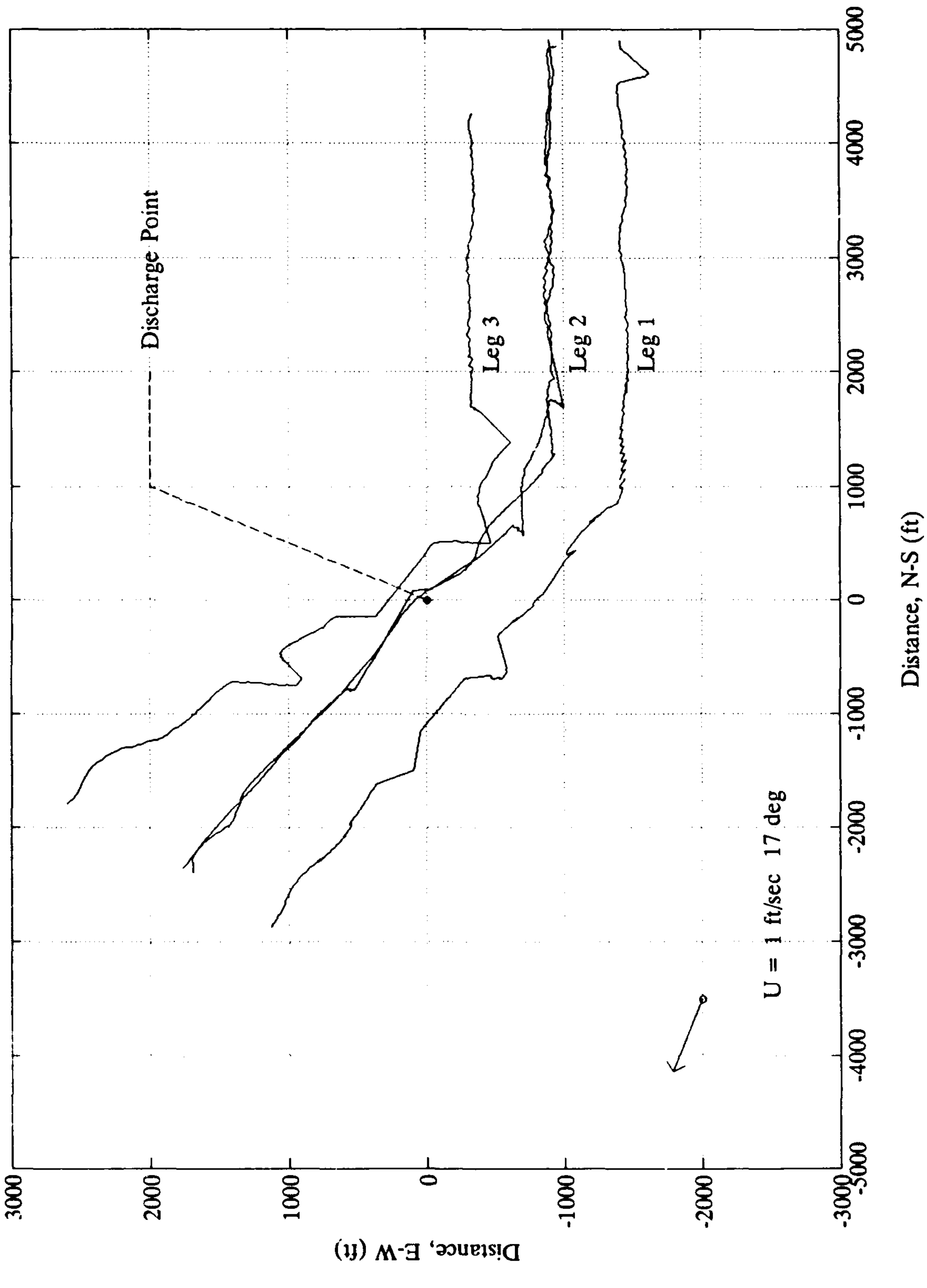
Survey # 1, 30 Sep 1991, Time: 09:53:36 to 10:20:35

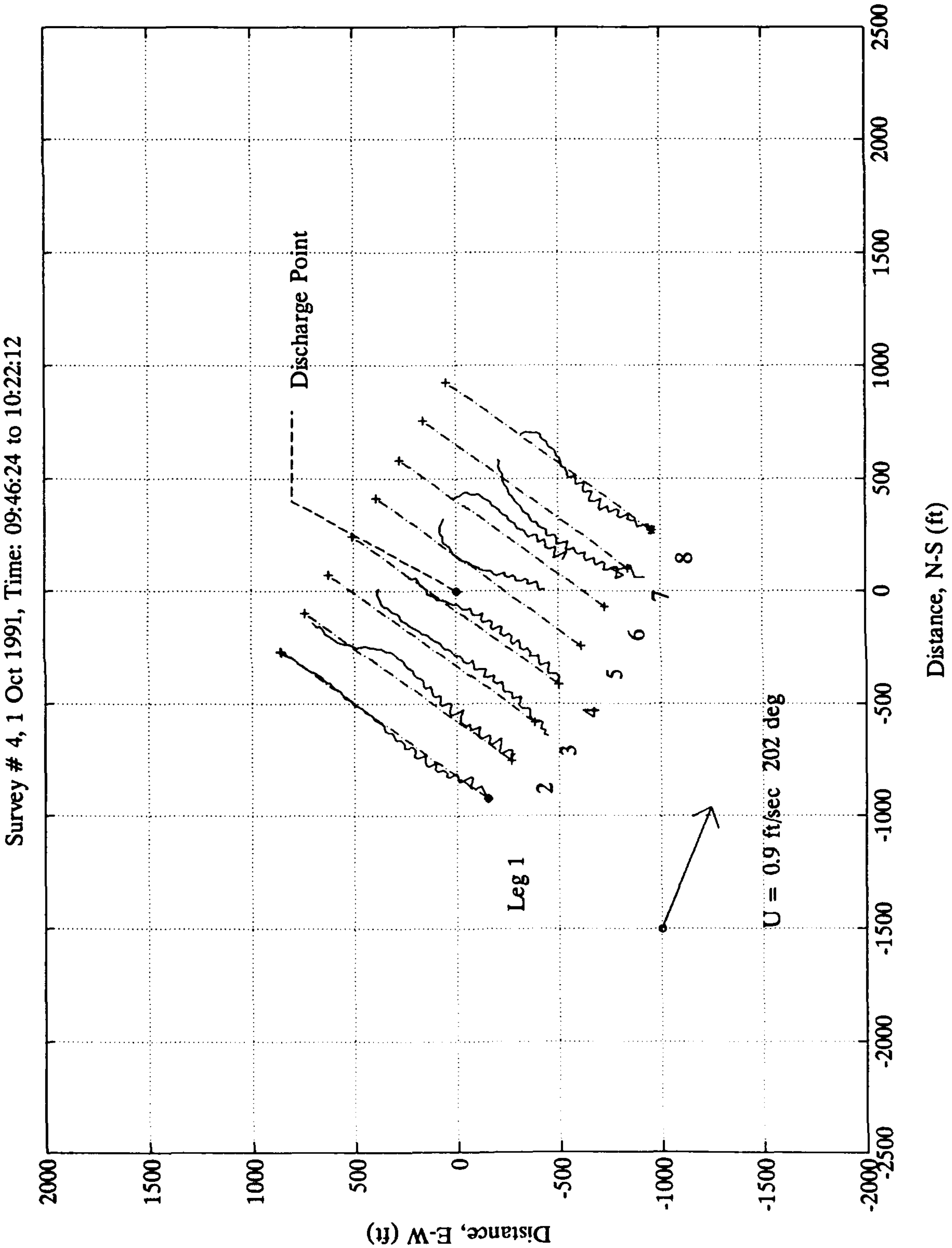




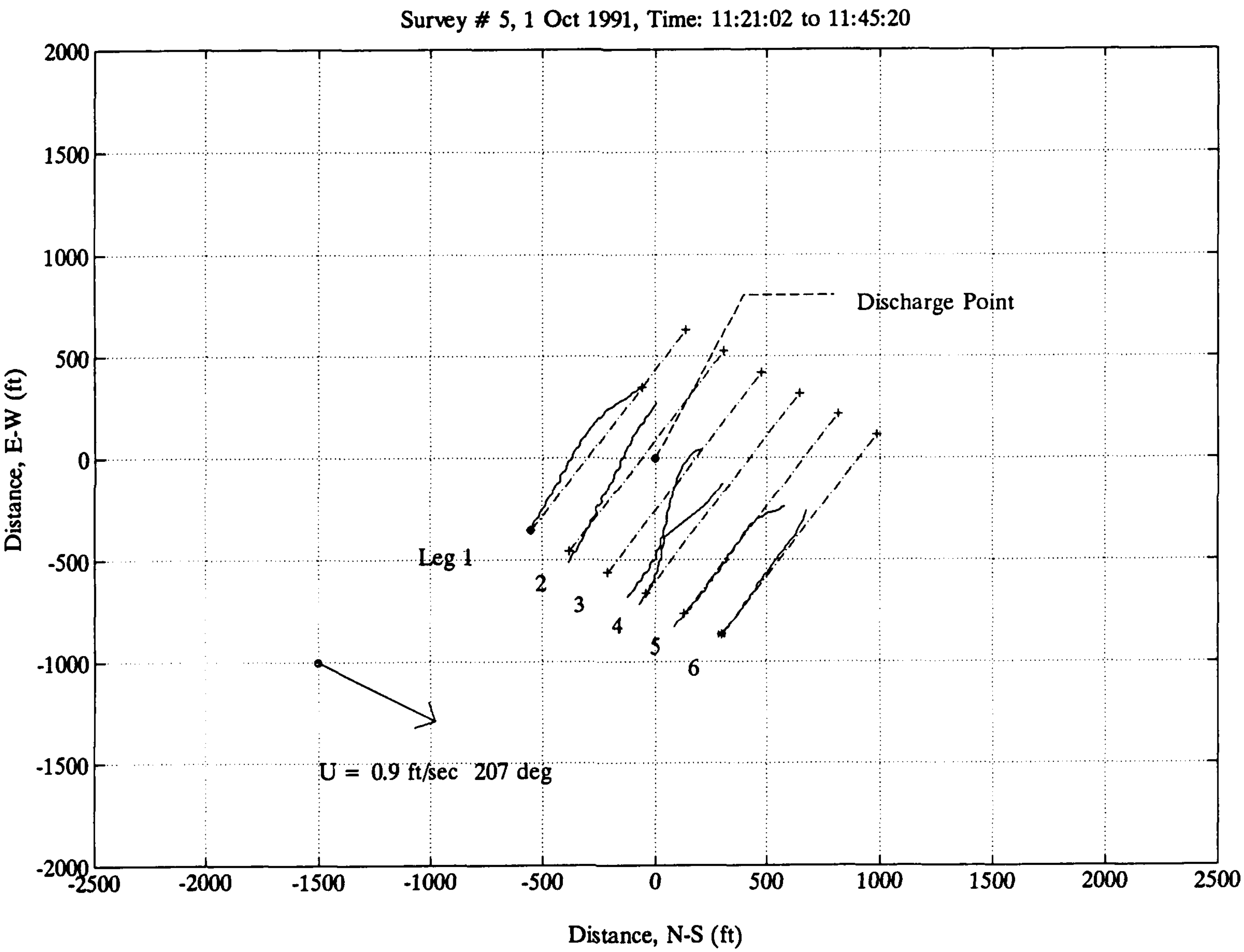
Survey # 2, 30 Sep 1991, Time: 12:30:36 to 13:16:00
Discharge Point
Leg 1
U = 0.8 ft/sec 19 deg
Distance, E-W (ft)
Distance, N-S (ft)
3000
2000
1000
0
-1000
-2000
-3000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000

Survey # 3, 30 Sep 1991, Time: 13:54:07 to 17:04:02

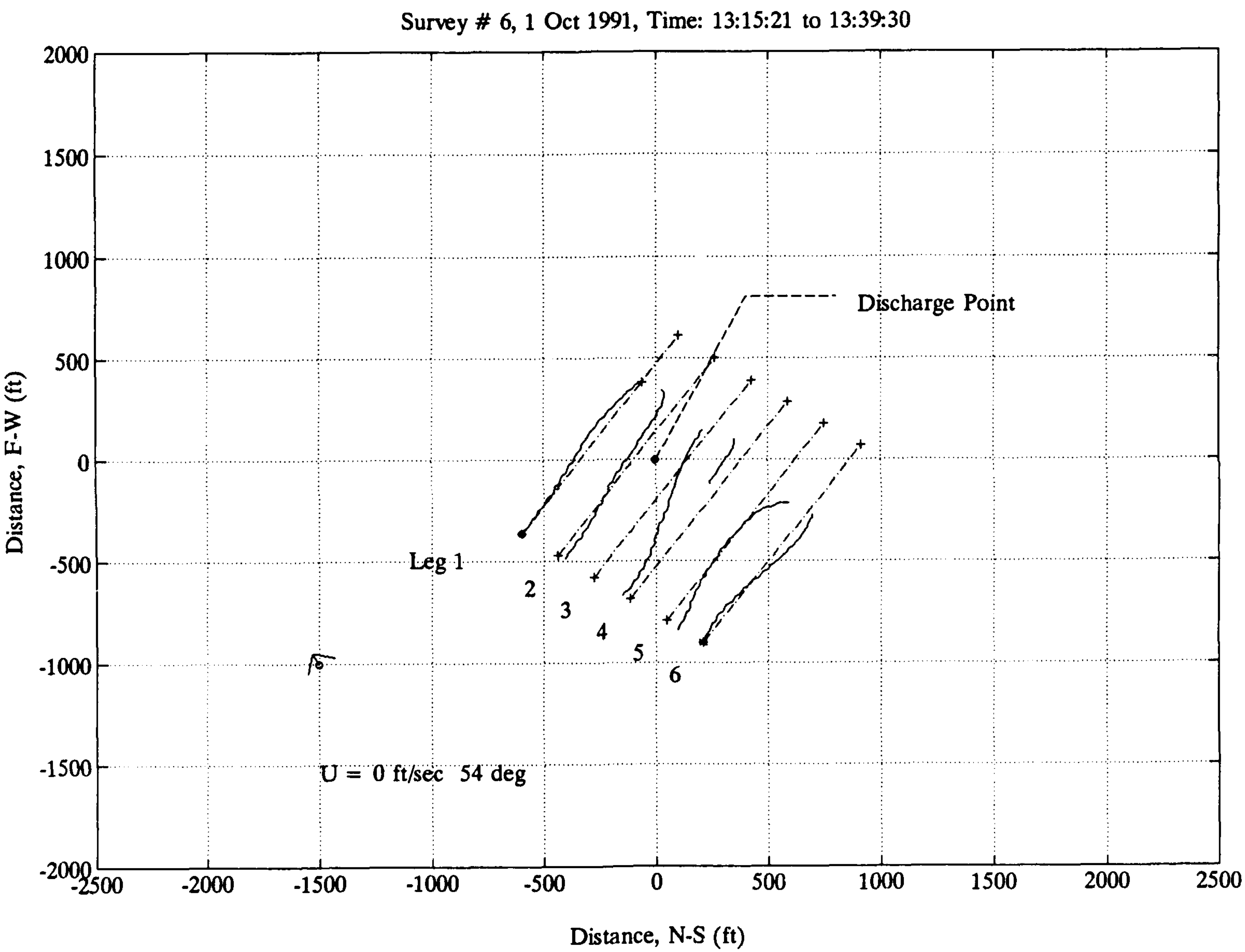




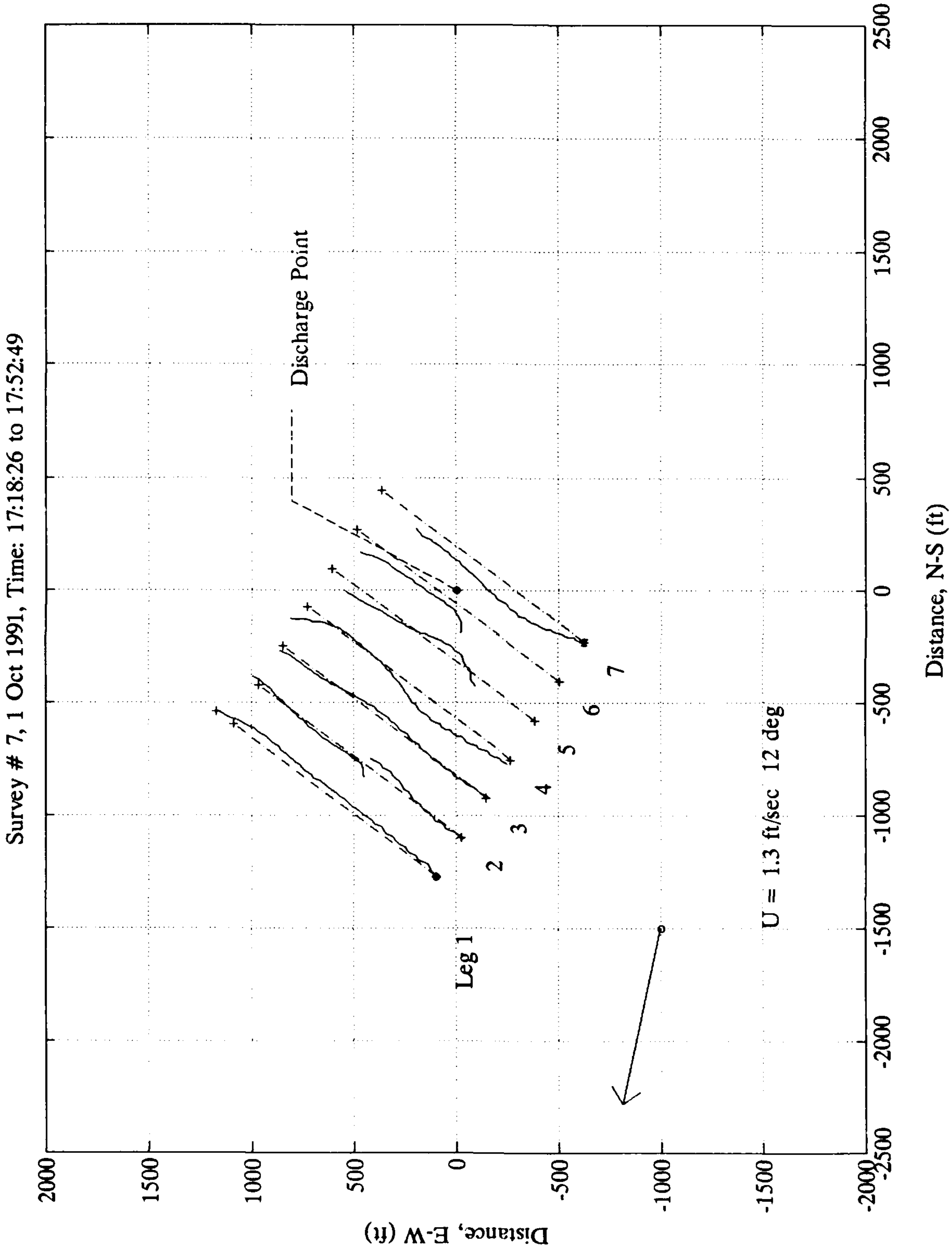
Survey # 4, 1 Oct 1991, Time: 09:46:24 to 10:22:12
Discharge Point
Leg 1
2
3
4
5
6
7
8
U = 0.9 ft/sec 202 deg
Distance, N-S (ft)
Distance, E-W (ft)
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

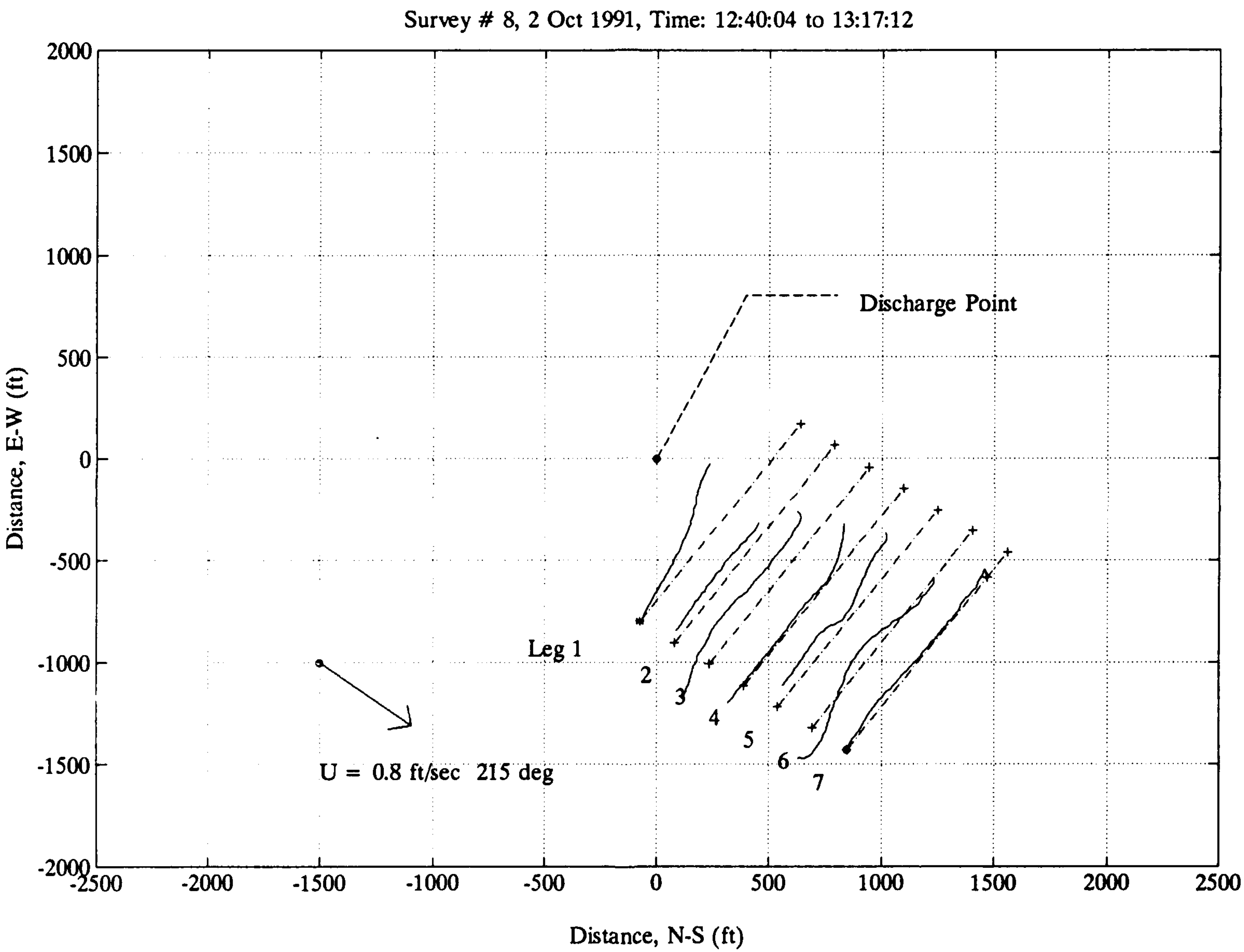


Survey # 5, 1 Oct 1991, Time: 11:21:02 to 11:45:20
Discharge Point
Leg 1
2
3
4
5
6
U = 0.9 ft/sec 207 deg
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
Distance, E-W (ft)
Distance, N-S (ft)

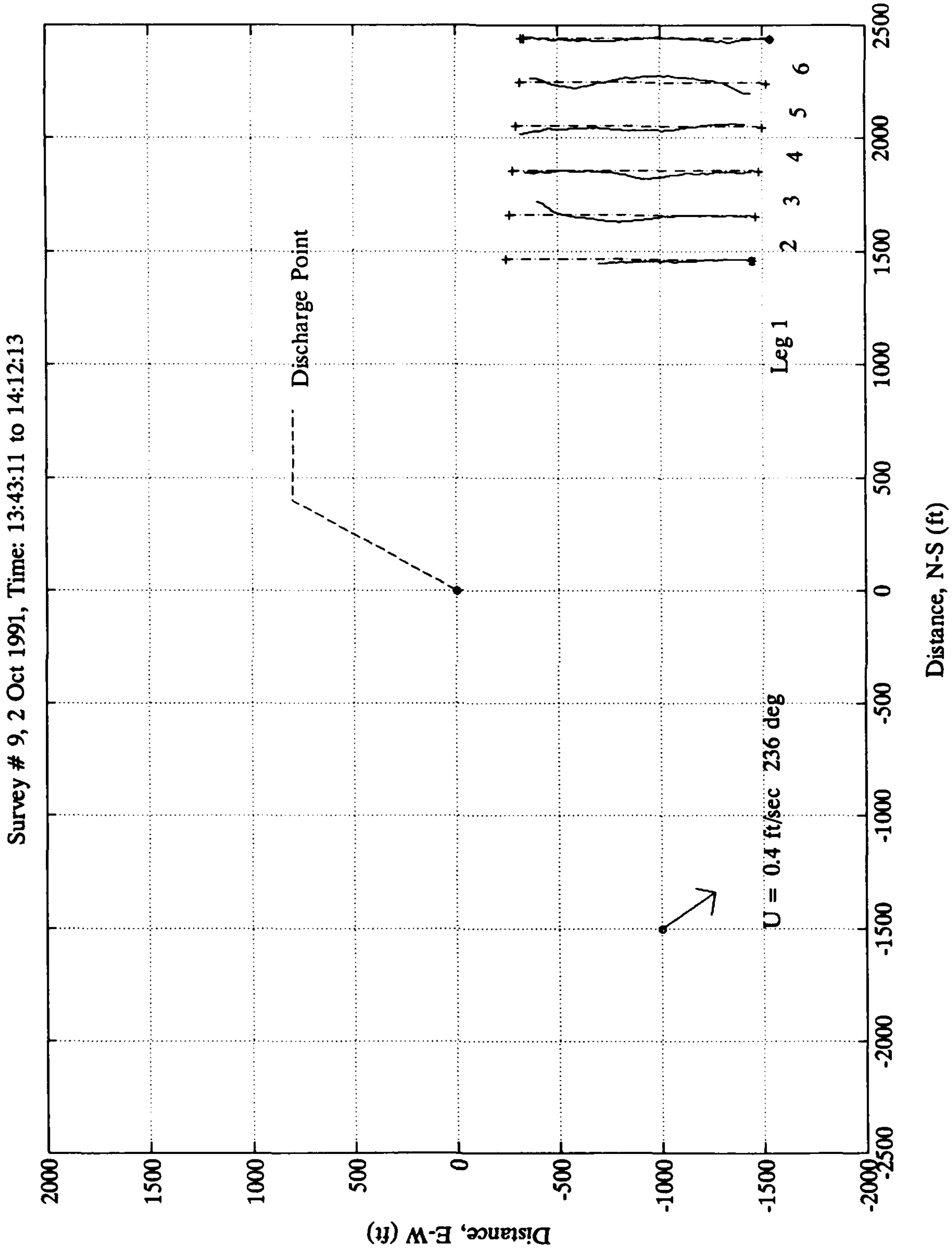


Survey # 6, 1 Oct 1991, Time: 13:15:21 to 13:39:30
Discharge Point
Leg 1
2
3
4
5
6
U = 0 ft/sec 54 deg
Distance, E-W (ft)
Distance, N-S (ft)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
2500

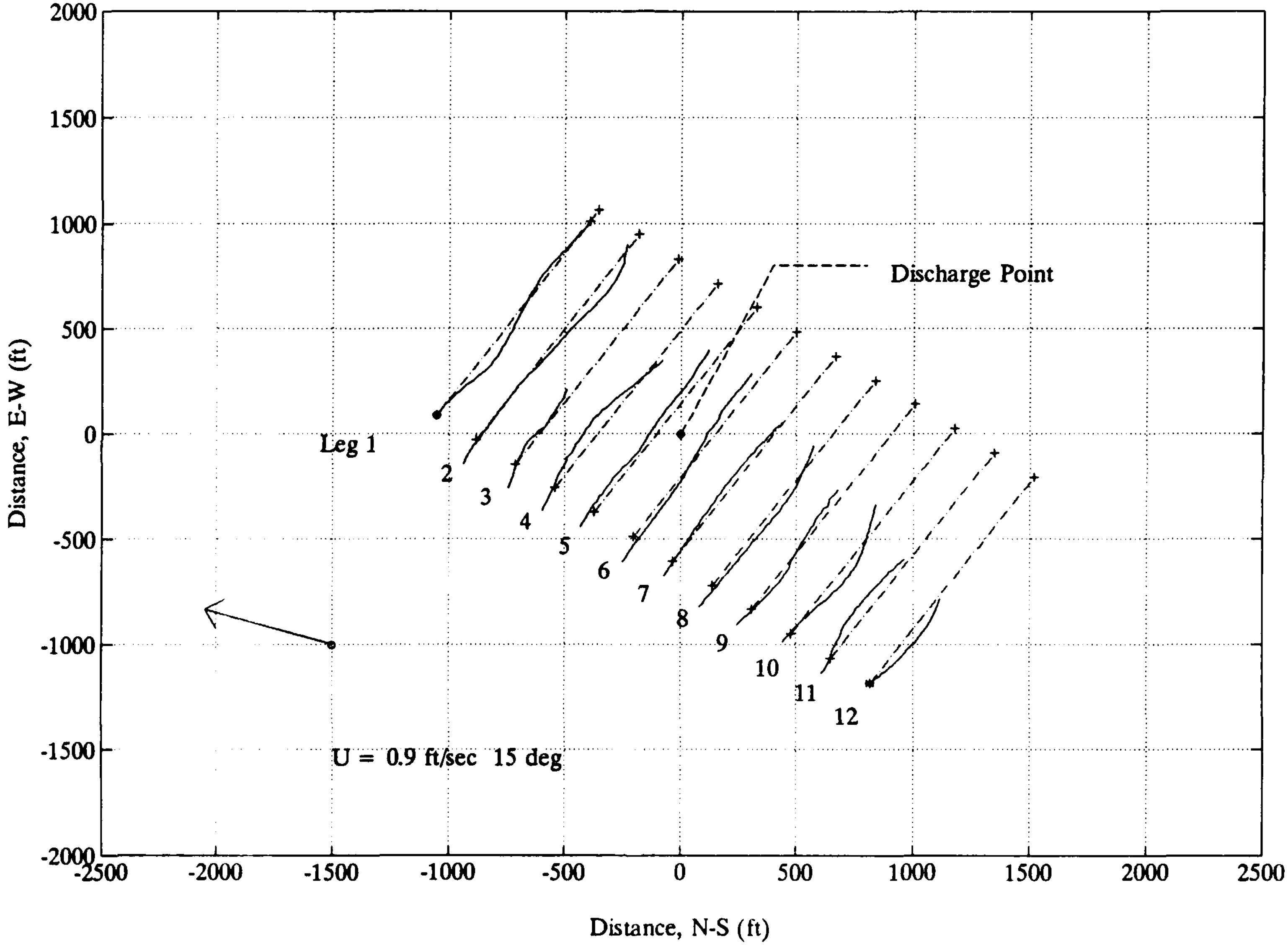

Survey # 7, 1 Oct 1991, Time: 17:18:26 to 17:52:49
Discharge Point
Leg 1
2
3
4
5
6
7
U = 1.3 ft/sec 12 deg
Distance, N-S (ft)
Distance, E-W (ft)
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000

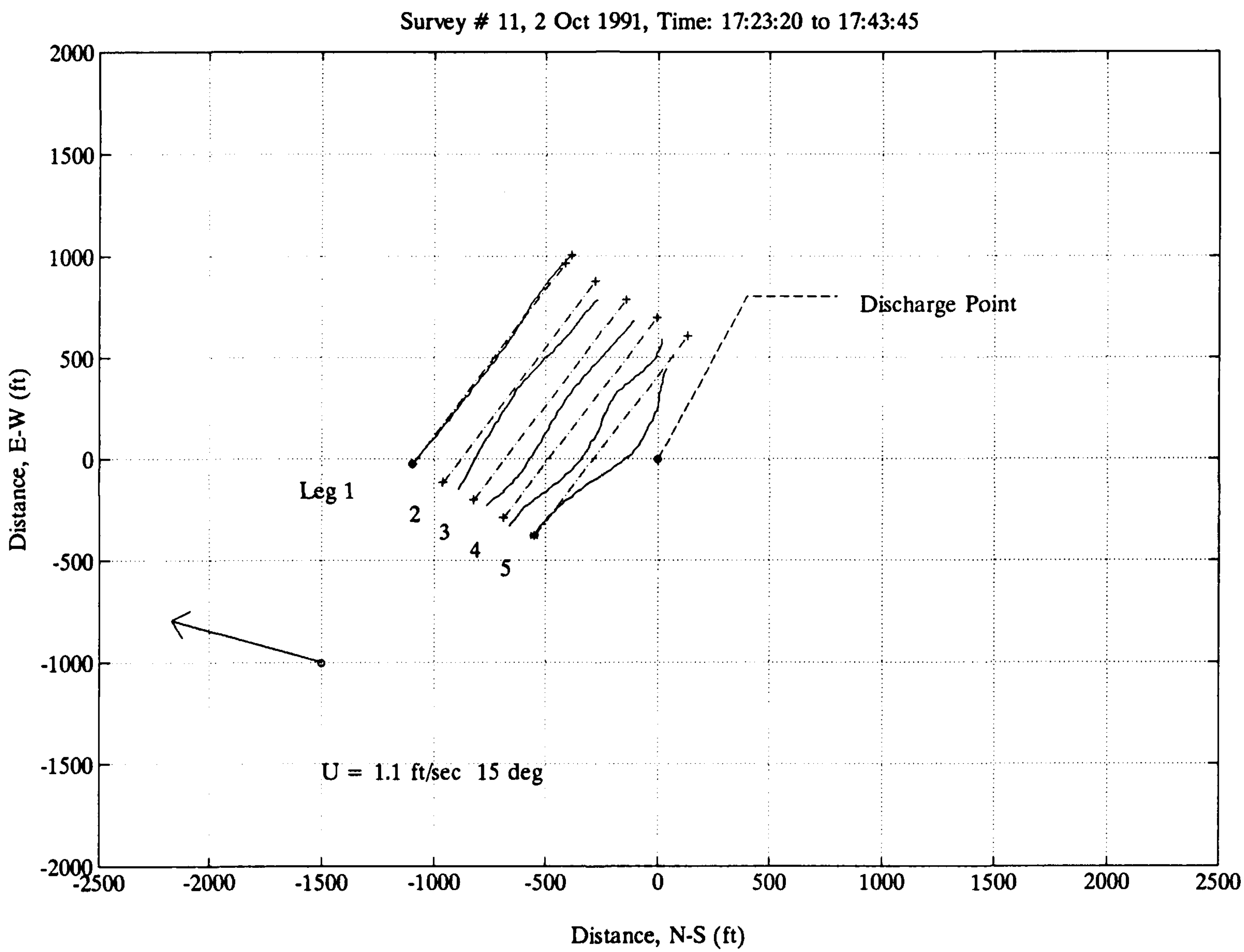


Survey # 8, 2 Oct 1991, Time: 12:40:04 to 13:17:12
Discharge Point
Leg 1
2
3
4
5
6
7
U = 0.8 ft/sec 215 deg
Distance, E-W (ft)
Distance, N-S (ft)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
2500

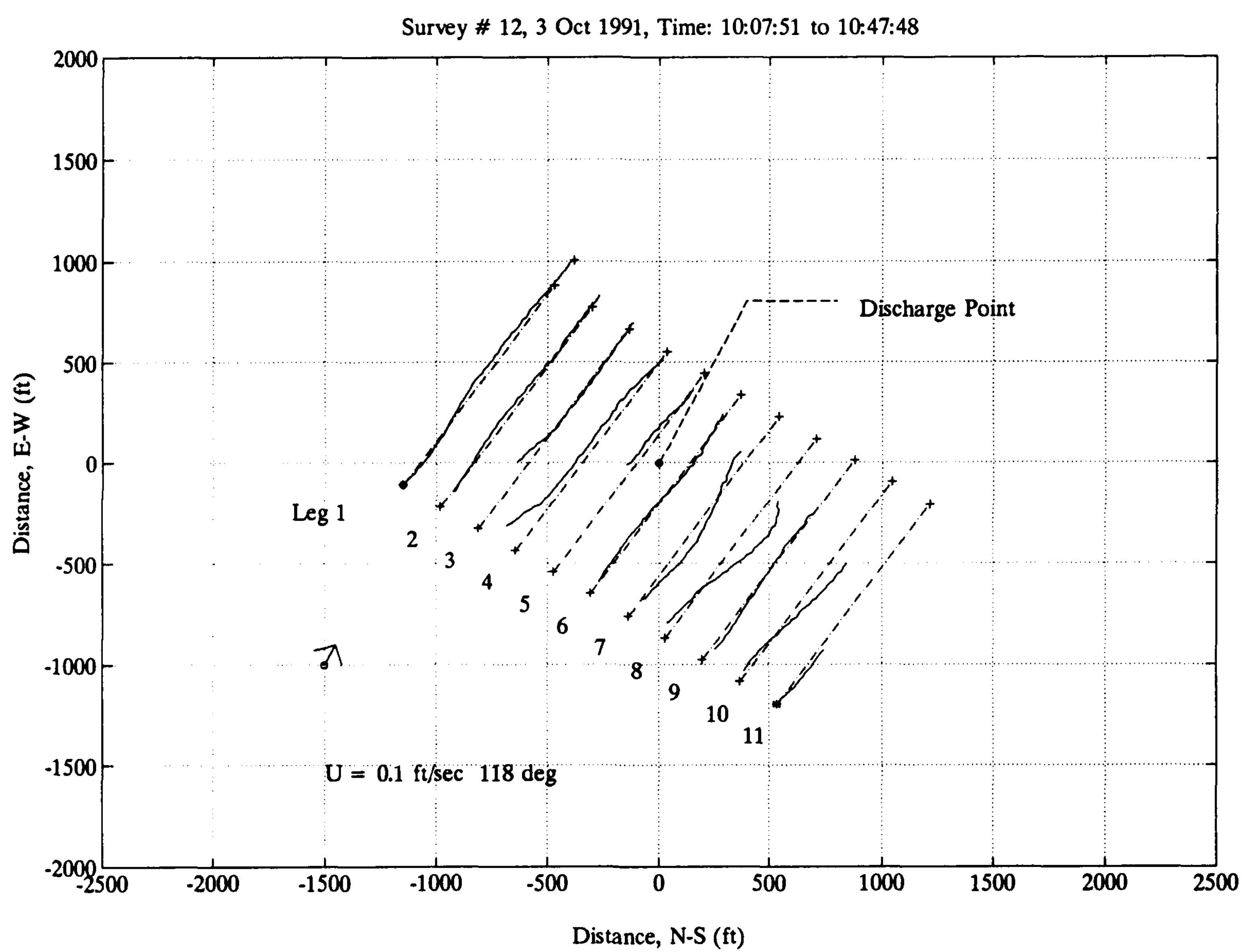

Survey # 9, 2 Oct 1991, Time: 13:43:11 to 14:12:13
Discharge Point
U = 0.4 ft/sec 236 deg
Leg 1
2
3
4
5
6
Distance, N-S (ft)
Distance, E-W (ft)
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

Survey # 10, 2 Oct 1991, Time: 16:09:24 to 16:45:45





Survey # 11, 2 Oct 1991, Time: 17:23:20 to 17:43:45
Discharge Point
Leg 1
2
3
4
5
U = 1.1 ft/sec 15 deg
Distance, E-W (ft)
Distance, N-S (ft)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500



Survey # 12, 3 Oct 1991, Time: 10:07:51 to 10:47:48
Discharge Point
Leg 1
2
3
4
5
6
7
8
9
10
11
U = 0.1 ft/sec 118 deg
Distance, E-W (ft)
Distance, N-S (ft)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

APPENDIX F: SUMMARY OF ACOUSTIC SURVEYS[1]

1. Twelve acoustic surveys were conducted during the Tylers Beach, Virginia, Dredged Material Plume Monitoring Project (TBMP). Background Surveys 1, 2, and 3 were conducted on 30 September prior to dredging and placement operations. Surveys 4 through 12 were conducted from 1 through 3 October during placement operations to monitor movement of the dredged material. The acoustic data taken during the 12 surveys were converted from backscatter intensity to suspended material concentration (mg/ℓ) using Equation 16 of this report. This appendix provides a summary of the acoustic surveys and corresponding legs.

Background Surveys, 30 September 1991

2. Background surveys were conducted in three 8,000-ft transects that follow the course of the relict channel (running approximately north to south) and are numbered by location. Leg 1 runs along the channel approximately 500 ft west of the discharge point. Leg 2 runs along the center of the relict channel through the deepest section and discharge point, and Leg 3 is located on the east side of the channel which borders Point of Shoals. All times refer to local Eastern Daylight Savings Time (EDT).

Survey 1

3. One transect was run along Leg 2, starting at 09:53:36 and ending at 10:20:35. The bay was at ebb tide with a current having speed of 0.8 ft/sec and direction of 197 deg (to the southwest). Low concentration, less than 10 to 20 mg/ℓ, was observed in the water column. A region of higher concentration, between 20 and 30 mg/ℓ, was also observed near the bottom toward the southern end of the leg.

Survey 2

4. One transect was run along Leg 1, starting at 12:30:36 and ending at 13:16:00, during slack water which occurred at approximately 1230. Low suspended material concentrations, less than 10 mg/ℓ, were observed in the southern portion of the leg throughout the water column and in the upper half of the northern part. Concentration in the lower half of the water column gradually increased toward the north end of the channel, reaching levels of 20 to 30 mg/ℓ.

---

[1]Written by Ms. Terri L. Prickett, Mr. Ramon G. Cabrera, and Ms. Michelle M. Thevenot.

Survey 3

5. Four transects, along Legs 2, 3, 2, and 1, respectively, were run starting at 13:54:07 and ending at 17:04:02. During this survey, the bay was beginning to flood after a slack tide which occurred at approximately 1230. Peak flood tide was reached at about 1630. The average current speed was 1.0 ft/sec moving at 17 deg (to the northeast).

6. Leg 2, run at the beginning of the survey, showed concentrations of 40 to 50 mg/ℓ throughout the water column in the deeper parts of the channel, with concentrations of 70 to 80 mg/ℓ close to the bottom. Lower concentrations, 10 to 20 mg/ℓ, were observed to the north and to the south.

7. Leg 3, along Point of Shoals, showed slightly higher concentrations, up to 60 mg/ℓ, throughout the water column in the middle and north portions of the leg with lower concentrations, approximately 10 to 20 mg/ℓ, toward the south.

8. Leg 2 was profiled a second time, approximately 2 hr after the survey started. Concentrations of 70 to 80 mg/ℓ were observed throughout in the deepest parts of the channel. Concentrations greater than 100 mg/ℓ were observed near the bottom in the middle and southern portions of the leg. In the southern part of the leg, concentrations in the upper half of the water column were approximately 10 to 30 mg/ℓ. Concentrations in the entire water column in the northern portion ranged from 30 to 50 mg/ℓ.

9. Leg 1, the last profile of the survey, showed maximum concentrations of 50 to 70 mg/ℓ in the lower half of the water column to the north, with somewhat lower concentrations of 30 to 50 mg/ℓ to the south. The upper half of the water column showed similar concentration levels of 10 to 20 mg/ℓ along the entire leg. During this leg, peak flood flow, which occurred at approximately 1630, was reached.

Surveys During Dredging Operations, 1 October 1991

Survey 4

10. Eight legs were run during this survey starting at 09:46:24 and ending at 10:22:12. Legs 1 through 4 were located north of the discharge point and Legs 5 through 8 were located south of the discharge point. The bay was at ebb tide with an average current speed of 0.9 ft/sec and moving 202 deg (to the southwest). Legs 1 and 2 showed low concentration, less than 20 mg/ℓ in the deeper channel area, with higher concentration, 50 to 60 mg/ℓ, toward the shore in the lower half of the water column. Leg 3 showed dredged material concentration of 30 to 50 mg/ℓ moving toward the

shore and at the bottom of the channel. As the *Lynnhaven* approached and moved past the discharge point, a column of dredged material descending into the placement site was seen in Legs 4 through 6, with concentrations increasing throughout the water column toward the shore to approximately 60 to 70 mg/ℓ near the bottom. The dredged material was acoustically observed against the wall of the channel formed by Point of Shoals, and no dredged material was observed above or on Point of Shoals. Legs 7 and 8 also showed higher concentration toward shore, and the dredged material accumulated on the bottom of the channel. The material observed in the acoustic plots near the bottom on the shore side of the channel did not appear to come from the discharge plume but seemed to be moved from the shore into the channel by the current.

Survey 5

11. Six legs were run, starting at 11:21:02 and ending at 11:45:20. Legs 1 and 2 were located north of the discharge point, and Legs 3 through 6 were located south of the discharge point. The bay was at ebb tide with an average current speed of 0.9 ft/sec and moving 207 deg (to the southwest). Concentrations of 10 to 20 mg/ℓ were observed in most of the water column and on Point of Shoals. Concentrations of 40 to 50 mg/ℓ were observed in the lower half of the water column toward the shore. Again, the material on the shore side did not appear to originate from the discharge plume. The profile of Leg 3, located near the placement site, showed the discharge plume descending to the bottom, as well as a considerable amount of accumulated sediment (at approximately the 6- to 8-ft depth) at the bottom of the site. Acoustic observations of the dredged material in Legs 4 through 6 showed the dredged material pushed against the foot of the Point of Shoals wall in the channel by the current.

Survey 6

12. Six legs were run, starting at 13:15:21 and ending at 13:39:30. Legs 1 and 2 were located north of the discharge point, and Legs 3 through 6 were located south of the discharge point. The tide was slack, reversing from ebb to flood tide with no measurable current. Legs 1 and 2 showed low concentration, less than 10 mg/ℓ throughout the water column and on Point of Shoals, except in the deepest part of the channel near the bottom, where concentration reached 60 to 80 mg/ℓ. All legs showed a layer of dredged material several feet thick, that accumulated in the deepest section of the channel. Legs 3 through 6 showed concentrations less than 10 mg/ℓ in most of the water column and on Point of Shoals. Concentrations greater than 100 mg/ℓ were observed above the layer of accumulated dredged material in the deeper sections of the channel. Legs 3 through 5 also showed a thin plume of dredged material extending from the surface to the site bottom in the center of the channel.

Survey 7

13. Seven legs were run, starting at 17:18:26 and ending at 17:52:49. Legs 1 through 6 were located north of the discharge point, and Leg 7 was located south of the discharge point. The bay was at a period of flood tide with an average current speed of 1.3 ft/sec and moving 12 deg (to the northeast). A layer of unsettled dredged material was acoustically detected on the western slope of the channel in Legs 1 through 4, and also on the middle of the channel in Legs 5 through 7. Legs 1 through 6 showed concentration from 10 to 40 mg/ℓ throughout the entire water column from the center of the channel to Point of Shoals. The shore side of the channel showed higher concentrations of 40 to 50 mg/ℓ near the surface in the center of the channel, increasing with depth to concentrations of 100 mg/ℓ near the bottom. Leg 7 showed lower concentrations of 10 to 20 mg/ℓ in the upper half of the water column in the center and shore side of the channel, which increased with depth, to 60 to 80 mg/ℓ near the bottom. Concentrations of 30 to 60 mg/ℓ were also observed in this leg on Point of Shoals.

Surveys During Dredging Operations, 2 October 1991

Survey 8

14. Seven legs were run, starting at 12:40:04 and ending at 13:17:12, and were located south of the discharge point. The tide was ebbing with an average current speed of 0.8 ft/sec and moving 215 deg (to the southwest). All legs of this survey showed increased concentration toward the shore side of the channel, with near-bottom concentrations of 40 to 60 mg/ℓ. Concentrations throughout the water column, in most legs, were approximately 10 to 20 mg/ℓ. Leg 1, located closest to the discharge point, showed a narrow dredged material plume descending from the surface to the site bottom. Leg 6 showed moderate concentration, from 20 to 40 mg/ℓ, in the water column on the Point of Shoals side. A layer of sediment up to 5 ft thick could be seen accumulated on the bottom of the channel and against the Point of Shoals wall, and was detected acoustically in several of the legs. Team 1 was unable to make further observations on Point of Shoals during this survey, because the water was too shallow for the *Lynnhaven* to navigate.

Survey 9

15. Six legs were run during this survey, starting at 13:43:11 and ending at 14:12:13. All legs were located south of the discharge point past the bend in the relict channel. The tide was ebbing with an average current speed of 0.4 ft/sec and moving 236 deg (toward the southwest). Low

concentration, less than 20 mg/ℓ, was observed in the upper half of the water column in the deepest section of the channel. Similar low concentration was observed throughout the water column on Point of Shoals. Gradually increasing with depth, concentrations of 30 to 40 mg/ℓ were observed near the bottom in the deeper portions of the channel. A thin layer of unsettled dredged material was observed acoustically on the bottom of the channel in Legs 1 through 3, and concentrations of approximately 20 mg/ℓ were observed in the lower half of the water column on the shore side.

Survey 10

16. Twelve legs were run during this survey, starting at 16:09:24 and ending at 16:45:45. Legs 1 through 5 were located north of the discharge point, and Legs 6 through 12 were located south of the discharge point. The system was at flood tide with an average current speed of 0.9 ft/sec and moving 15 deg (to the northeast). Dredging operations stopped at approximately 1620 EDT during Leg 4 and resumed at approximately 1650 EDT, after this survey was completed. Legs 1 and 2 showed concentrations of 40 to 60 mg/ℓ near the bottom in the middle and shore side of the channel. Concentrations in the upper half of the water column and on Point of Shoals were less than 20 mg/ℓ. Legs 4 through 12 showed a layer of accumulated dredged material on the bottom of the channel spreading from the center to the shore side. Concentration above this layer reached levels of 60 to 80 mg/ℓ. Little material was observed against the Point of Shoals wall. In Legs 3 through 10, concentration in the upper half of the water column fluctuated between 10 and 40 mg/ℓ. On Point of Shoals, the suspended material concentration was less than 20 mg/ℓ for all legs.

Survey 11

17. Five legs were run during this survey, starting at 17:23:20 and ending at 17:43:45. All legs were located north of the discharge point. The tide was flooding, with an average current speed of 1.1 ft/sec and moving 15 deg (to the northeast). Legs 1 and 2, from the middle of the channel to the shore side of the channel, showed concentrations of 20 to 40 mg/ℓ close to the surface and 70 to 90 mg/ℓ near the bottom. Low concentrations, 10 to 20 mg/ℓ, were detected throughout the water column from the center of the channel to the Point of Shoals side. Legs 3 through 5 showed accumulation of dredged material in a layer on the bottom of the channel and on the western slope. Those legs also showed low concentrations, 10 to 20 mg/ℓ, throughout the water column to the east and on Point of Shoals. Concentration on the west side of the channel varied from 20 to 40 mg/ℓ close to the surface to approximately 80 to 100 mg/ℓ near the bottom. The center of the channel showed concentrations ranging from 30 to 70 mg/ℓ throughout the water column.

Surveys During Dredging Operations, 3 October 1991

Survey 12

18. Eleven legs were run during this survey, starting at 10:07:51 and ending at 10:47:48. Legs 1 through 5 were north of the discharge point and Legs 6 through 11 were located south of the discharge point. The tide was slack, reversing from flood to ebb tide with an average current speed of 0.1 ft/sec and moving 118 deg (to the southeast). The dredge was not operating at 0945 when the field team reached the project site and throughout this acoustic survey. All legs showed concentrations less than 20 mg/ℓ in the upper half of the water column. Concentration increased with depth from approximately 20 mg/ℓ at the 10- to 12-ft depth to 40 to 50 mg/ℓ near the bottom. A thin layer of unsettled dredged material was also observed in the deepest sections of the channel. The suspended material concentration was similar to the concentration of background measurements taken during slack water above the 12-ft contour. The concentration was higher at the bottom of the placement site. This implies that shortly after placement is ceased, concentrations in the upper water column return to a range similar to those found during background monitoring.

APPENDIX G: NOTATION

A Area of discharge port, m^2

B Buoyancy parameter for discharge, m^4/sec^3

BL Backscatter level, dB

C Suspended material concentration, kg/m^3 or mg/ℓ

D Water depth, m

E Entrainment flux, $kg/m^2/sec$

EL Echo level measured at the transducer, dB

Fn Froude number

F_p Force acting on edge of underflow, N

F_t Force acting on bottom of underflow, N

I_i Intensity of incident signal, W/m^2

I_r Intensity of reflected signal, W/m^2

Is_i Intensity of incident signal for a single particle, W/m^2

Is_r Intensity of reflected signal for a single particle, W/m^2

K Empirical coefficient for buoyancy flux

K_1 Empirical coefficient relating backscatter level to volume scattering strength

K_2 Empirical coefficient relating concentration to backscatter level

M Momentum parameter for discharge, m^4/sec^2

P Depositional probability

Q Discharge flow rate, m^3/sec

Q_s Discharge or dispersion rate for sediments, kg/sec

Q_u Underflow flow rate, m^3/sec

Q^* Non-dimensional buoyancy flux

R Radius of underflow, m

R^2 Correlation coefficient

Re Reynolds number

Ri Richardson number

SL Source level of the transducer, dB

S_v Volume scattering strength referenced to a volume of 1 m^3, dB

T Transmissivity, volts

Ts	Target strength, dB
TL	Transmission loss, dB
U	Current speed for ambient flow, m/sec or ft/sec
U_u	Spreading rate for underflow, m/sec
$U_u(r)$	Underflow depth-averaged current speed at radial distance, m/sec
U_x	Depth-averaged current speed in X direction, m/sec
V_e	Ensonified volume, m^3
V	Underflow volume, m^3
V_s	Dispersion velocity, m/sec
W	Vertical current, m/sec
W_i	Hindered settling index speed, m/sec
W_s	Settling speed, m/sec
$\overline{W'C'}$	Vertical flux component due to interfacial instabilities, $kg/m^2/sec$
X	Horizontal coordinate in the direction of flow, m
Y	Horizontal coordinate in the direction normal to the flow, m
Z_b	Length scale for buoyancy, m
Z_m	Length scale for momentum, m
b	Jet radius, m
g	Acceleration of gravity, m/sec^2
h	Underflow thickness, m
k	Inverse of fully-settled sediment concentration, ℓ/g
k_1	Empirical parameter for the complete suppression of entrainment
k_2	Empirical parameter for no effect of viscosity on entrainment
m	Mass, kg
r_e	Range, m
r	Radial distance from center of underflow, m
s	Distance along plume trajectory, m
t	Time, sec
z	Vertical dimension, m
η	Viscosity, Pa-sec
ρ_o	Density of ambient fluid, kg/m^3
ρ_m	Density of fluid mud, kg/m^3

τ Bed shear stress, N/m^2

τ_{cd} Critical shear stress for deposition, N/m^2

α Attenuation coefficient, dB/m

Waterways Experiment Station Cataloging-in-Publication Data

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